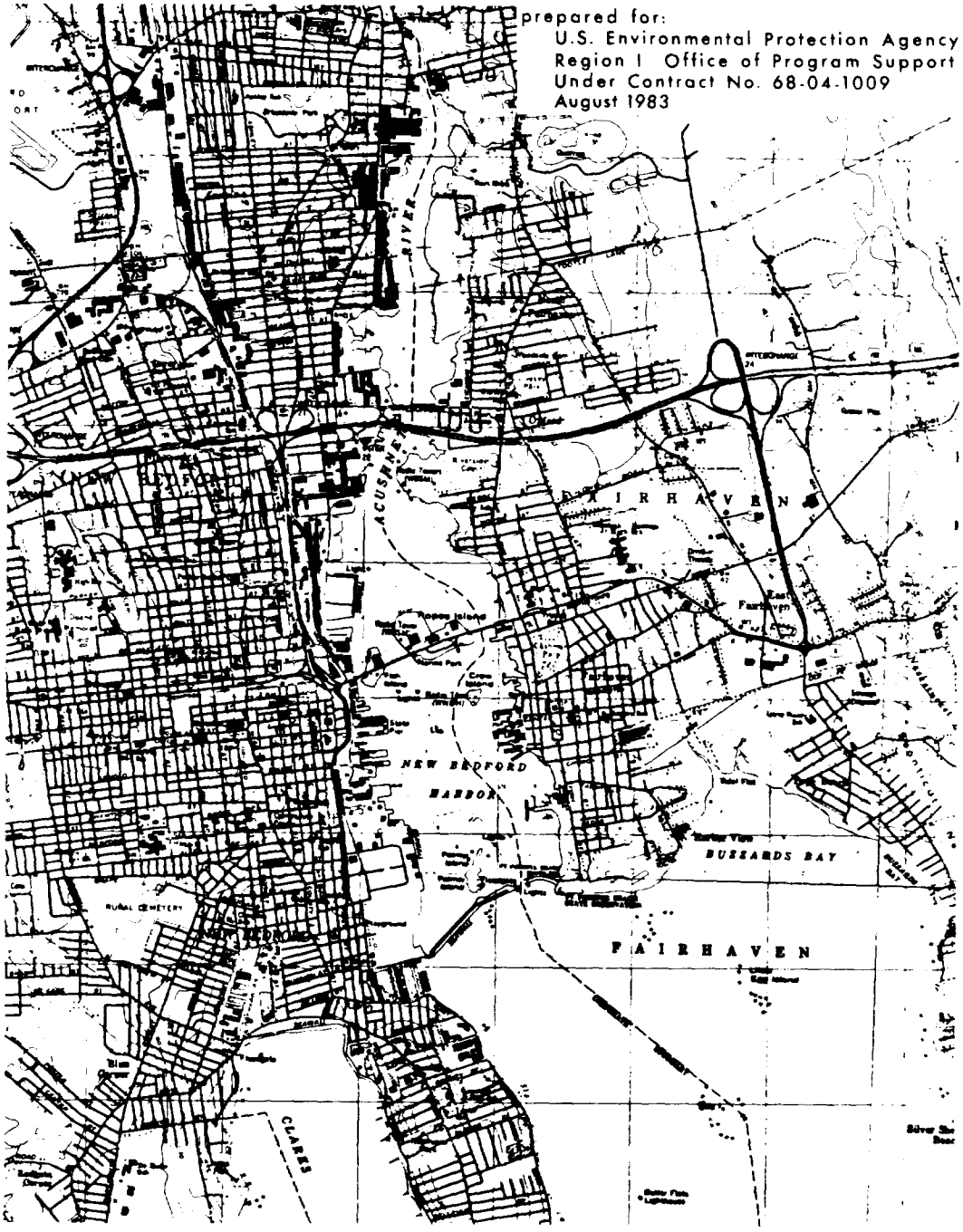
ACUSHNET ESTUARY PCBs
DATA MANAGEMENT
FINAL REPORT

prepared for:
U.S. Environmental Protection Agency
Region I Office of Program Support
Under Contract No. 68-04-1009
August 1983



EPA

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September 16, 1983

Mr. Robert E. Mendoza, Project Officer
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U.S. Environmental Protection Agency, Region I
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Boston, Massachusetts 02203

Dear Mr. Mendoza:

As a part of work conducted under Work Order No. 8, U.S. EPA Contract No. 68-04-1009, it is our pleasure to submit the attached "ACUSHNET ESTUARY PCBs DATA MANAGEMENT, FINAL REPORT."

The PCB Data Management System was devised in response to a need to organize a large volume of PCB related data from the environmental measurements taken in the Acushnet Estuary, Massachusetts area. Based on compilation of over 5000 data entries from twenty-three different analytical laboratories and twenty-one different agencies, the system was used to characterize the data for its analytical and field collection reliability. Following the assessment for reliability, all data were coded and entered into the system. Based on the reliable data (over ninety percent of all the observations), analyses were conducted to identify the type, location and extent of contaminated areas, and delineate areas where additional data was required. Statistical analyses of the data were also conducted to delineate significant changes over time, as well as to identify "hot spots" where more immediate remedial action may be required.

This report summarizes key physical, chemical and biological properties of PCBs which affect their transport and fate in the environment. Utilizing this technical foundation, the report contains an assessment of the PCB data for use by State and Federal regulatory agencies in the conduct of activities related to implementation of effective remedial action in the Acushnet Estuary area.

Metcalf & Eddy, Inc., is pleased to have been a part of the very large team of Federal, State, and private agencies and institutions that have been able to contribute to the administrative and informational needs for effective remedial action in the Acushnet area.

Very truly yours,

Robert J. Reimold

Robert J. Reimold, Ph.D
Project Manager

RJR:dmr

attachment

PREFACE

The work described in this report was performed under Work Order No. 8, Contract No. 68-04-1009, entitled "Preparation of Environmental Impact Statements and NEPA Related Studies for Region I," dated June 1981, between the U.S. Environmental Protection Agency (EPA), and Metcalf & Eddy, Inc. (M&E).

This report was prepared for the Office of Program Support, EPA, Region I. The Project Officer responsible for overall coordination of this work was Mr. Robert E. Mendoza. The Project Manager responsible for EPA's daily management of the work was Mr. Kenneth H. Wood.

The Metcalf & Eddy, Inc. author of this report was Ms. Elizabeth D. Eggleston. Technical support documentation and preparation of draft material was provided by: Ms. Kathleen A. Smith; Ms. Melanie Byrne Thomas, Mr. Paul Geoghegan, and Ms. Christine Rosinski. Technical review of the work was conducted by: Dr. Abu M. Z. Alam, Mr. David P. Bova, Mr. Donald M. Brailey, Dr. Edward J. Chichon, and Mr. James G. Dedes. Technical support related to Kriging was provided by Mr. David Hergert and Mr. Reuel Warkov (Avco Computer Services). Dr. Robert J. Reimold served as Project Manager for this work; the M&E Principal responsible for this work was Mr. Richard L. Ball, Jr. Vice President.

This report has been reviewed and approved for publication by Metcalf & Eddy and the U.S. Environmental Protection Agency. Approval does not signify that the contents necessarily reflect the views and policies of EPA, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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INTRODUCTION

Ever since polychlorinated biphenyls (PCBs) were first identified in a wide variety of environmental samples, as a bias in pesticides analysis (Jensen, 1966), much has been written regarding the distribution, fate and effects of these compounds in the environment. Soon after the first published reports of PCBs found in marine and estuarine ecosystems (Jensen et al., 1969), it was recognized that they may pose a health hazard in the environment. The death of over 1000 Japanese people due to consumption of PCB contaminated rice oil (Kuratsune, 1969); increased kit mortality in domestic mink, whose mothers had been fed a diet including PCB containing salmon (Aulerich et al., 1971); and the chronic toxicity of chickens exposed to a feed room painted with paint containing a PCB binder (Gustafson, 1970), quickly focused public attention on the diverse adverse impacts of PCBs in the environment.

In New England, an areawide survey conducted in 1976 by the U.S. Environmental Protection Agency (EPA, 1976) first identified PCB contamination in the Acushnet Estuary, adjacent to New Bedford and Fairhaven, Massachusetts. High levels of PCBs were found in a variety of environmental samples. Since that time, extensive sampling efforts have been conducted in the Acushnet Estuary area by numerous Federal, State, local, and private organizations to determine the environmental fate, effects and sources of the PCBs.

In reviewing the industrialization of the Acushnet Estuary area, possible sources of PCB contamination were identified. Major users of PCBs include two electrical capacitor manufacturers, Aerovox Incorporated and Cornell-Dubilier Electronics Corporation, who actively discharged PCBs to the estuary and to the municipal sewerage system from the time their operations commenced in the 1930's until 1977, when the use of PCBs was banned by the U.S. EPA. Other minor users of PCBs were also identified. Also during that time, PCB-contaminated waste capacitors as well as dredged material from the harbor were buried at the city landfill, an upland dump site known as Sullivan's Ledge, and at several other unidentified sites in the New Bedford vicinity. Dredged materials were also used as fill for numerous building sites throughout the city.

There is currently a pervasive PCB pollution problem throughout the Acushnet Estuary area. Concentrations in the sediments underlying the 985 acre harbor range from < 1 to almost 200,000 ppm (dry wt.) PCBs. Portions of Buzzards Bay are also contaminated, with concentrations in excess of 50 ppm. Samples taken from within the sewerage system and the municipal wastewater treatment plant contain high PCB levels, as do air samples in the vicinity of the sludge incinerator. Sediment, groundwater and air PCB contamination have also been documented at the landfill and Sullivan's Ledge sites. In addition, a small scale health study by the Massachusetts Department of Public Health revealed elevated blood levels of PCBs in local residents.

and thus became eligible for Superfund assistance. Subsequently, a Remedial Action Master Plan (RAMP), outlining the strategy for further sampling and investigation of cleanup alternatives was prepared (Weston, 1983). The RAMP document summarized t' information needs, and described the actual remedial action model and the administrative requirements, for conduct of the work.

Metcalf & Eddy, Inc.'s involvement in the Acushnet Estuary study began in January, 1982, with an EPA Work Order (under the U.S. EPA Region I, Office of Program Support, Mission Contract) to institute a computerized Data Management System to handle the large volume of PCB-related data for the Acushnet Estuary area. This project entailed compilation of all the readily available data; development of 30 categorical data fields to describe the data; coding; and entering them into a computer software package (DATATRIEVE-11). The system, described previously (Metcalf & Eddy, Inc., 1982), is a computerized data base that has been continuously reviewed and updated since its initiation, and presently contains over 5000 data entries.

As an integral part of the development, implementation and use of the data management system, numerous references to the behavior and characteristics of PCBs, and their presence in other ecosystems, were reviewed. This was essential to develop an understanding of the data and a perspective as to the identification of critical data deficiencies and prioritization for remedial action. The objectives of this report are to:

1. summarize the comprehensive data base on contaminants (PCBs and heavy metals) in the Acushnet Estuary environment;
2. characterize the data for use in remedial action and resource management planning;
3. identify the type, location, and extent of highly contaminated areas;
4. identify any critical deficiencies in the data base that would preclude the cost-effective and timely development and implementation of remedial action.

In order to attain these objectives, this report summarizes selected key physical, chemical and biological properties of PCBs which affect their transformation, transport, fate and effects in the environment. It is not, however, a comprehensive literature review. The report also contains an assessment of the Acushnet Estuary PCB data base, utilizing the above described background information to identify specific considerations and gaps in the data. The ultimate goal of this report, and the data management project undertaken by Metcalf & Eddy, at the request of the U.S. EPA Region I Office of Program Support, is to assist State and Federal agencies in the organization, analysis, and meaningful interpretation of all existing Acushnet Estuary PCB-related data; a necessary prerequisite to the development of appropriate remedial actions.

SECTION 1

SECTION 1 - LITERATURE REVIEW

Chemical and Physical Characteristics of PCBs

Polychlorinated biphenyls, or PCBs, are a class of compounds produced by the partial or complete chlorination of the biphenyl molecule. Over 200 PCB isomers (similar molecules with differing configurations) exist. The PCBs manufactured by Monsanto Corporation, under the trade name Aroclor, are mixtures of these isomers. With the exception of Aroclor 1016, the four-digit number which follows the Aroclor name characterizes the specific blend. The first two digits identify the product as a biphenyl, and the second two express the average approximate percentage (by weight) of chlorine in the blend. Thus, Aroclor 1242 is a biphenyl blend with approximately 42 percent chlorine content. The only exception to this protocol is Aroclor 1016, which is a biphenyl blend with approximately 41 percent chlorine. While the Aroclors containing 48 percent and less chlorine are colorless mobile oils, those with higher chlorine content are viscous liquids (Aroclor 1254) or sticky resins (Aroclors 1260 and 1262).

The physical and chemical properties of PCBs determine the nature and extent of their chemical behavior and, consequently, the transformation and transport processes they will undergo in the environment. The physicochemical properties of PCBs which affect their chemical interactions are summarized in Table 1. Since each Aroclor is a PCB blend, and is not a pure substance, it will behave slightly differently depending on its specific

TABLE 1. PHYSICOCHEMICAL PROPERTIES OF PCBs

Property	Aroclor Blend						
	1016	1221	1232	1242	1248	1254	1260
Molecular[a] weight range				154-358	222-358	290-392	324
Molecular[a] weight average				262	288	324	370
% Chlorine[b]	41	20.5-21.5	31.4-32.5	42	48	54	60
Vapor Pressure (25°C)[b] (mm_iHg)	[4 x 10^{-4}][c]	[6.7x10^{-3}]	[4.06x10^{-3}]	4.06x10^{-4}	4.94x10^{-4}	7.71x10^{-5}	4.05x10^{-5}
Vapor Pressure (38°C)[a] (mm_iHg)				10^{-3}	3.7 x10^{-4}	6 x10^{-5}	2 x10^{-7}
Solubility in Water[b] (mg/l)	0.42	[15.0]	[1.45]	0.24 0.34 0.13	0.054	0.012 0.024 0.056	0.0027
Solubility in Water[a] (at 20° C, ppm)				0.2	0.1	0.5	[0.025]
Log Octanol/Water Partition Coefficient[b] (K_{ow})	4.38 75.58	[2.8] 4.09	[3.2] 4.54	4.11 5.58	[5.75] 6.11	[6.03]	[7.14] 6.11
Henry's Law Constant[d]	(1.4±0.7)x10^{-2}	(7.4±10)x10^{-6}		5.7x10^{-4}		2.8x10^{-3}	
(H, atm m^3/mole)	(2.7±0.5)x10^{-6}			(7.6±4.5)x10^{-3}			
Air/Water Partition[d] Coefficients (atm m^3/mole)				(2.8±1.8)x10^{-7}		(1.4±0.7)x10^{-2}	
Liquid-Phase Mass-Transfer[d] Coefficient (K_{ol})m/n	(7.9±8.3)x10^{-2} (8.7±1.6)x10^{-4}	(8.9±0.6)x10^{-4}	5.7x10^{-2} (8.3±8.5)x10^{-2}			6.7x10^{-2}	

a. Wisbet and Sarofim, 1972
b. Versar, Inc.
c. All bracketed data are estimated.
d. Doskey and Andren, 1981. Experimentally and theoretically derived data.

composition of chlorinated biphenyl groups. The physical and chemical properties of PCB isomers depend on the intramolecular positions of substitution as well as the total chlorine content (Callahan et al., 1979; Zitko, 1980). In evaluating environmental samples therefore, it is important to know the relative quantities of individual blends and isomers, in order to permit more precise conclusions concerning their fate and effect. Where possible, this report will distinguish between the properties of specific isomers and those of the Aroclor blends.

Commercial PCB mixtures have been found to contain toxic substances other than PCBs. Specifically, polychlorinated dibenzofurans (PCDFs) have been detected in a number of domestic and foreign mixtures (EPA, 1976, 1980), as have polychlorinated naphthalenes (PCNs) (EPA, 1980). The possibility of polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated quaterphenyls (PCQs) also being present in commercial PCB mixtures has been raised, however, there appear to be no authenticated reports of this occurring. The potential presence of any of these highly toxic compounds in PCB mixtures complicates both their quantification and toxicological evaluation.

Physical Transformations

PCBs are aromatic, strongly hydrophobic compounds, (i.e. they tend to repel water molecules), and have a low solubility in water. In relatively non-polar organic solvents and lipids in biological systems, PCBs are freely soluble (EPA, 1980). Water

solubility decreases with increasing chlorination, but given that specific PCBs are mixtures of different chlorinated biphenyl species, the solubility is an average of the component species. Measured and estimated PCB water solubility values range from 15.0 mg/l for Aroclor 1221 to 0.0027 mg/l for Aroclor 1260 (Callahan et al., 1979; see Table 1). The equilibrium of PCBs in water is time-dependent, and measured values range from 2 to 5 months for the various isomers to reach equilibrium (Haque, 1980; Rappe, 1979).

A compound's vapor pressure influences its rate of evaporation from environmental media. The persistance of PCBs in soil and surface water, and their tendency to move between environmental compartments, including the atmosphere, are highly dependent on this chemical-specific property (Lyman et al., 1982). The vapor pressures of PCBs are low, with values ranging from 6.7×10^{-3} atm (Aroclor 1221) to 4.05×10^{-5} atm (Aroclor 1260) (Callahan et al., 1979; Nisbet and Sarofim, 1972).

Volatilization is the process by which a compound enters the atmosphere as a vapor from another environmental compartment, and it is an important mass transfer pathway from soil and surface water to air. The rate at which a chemical volatilizes from soil or water is affected by many factors, including the chemical and physical properties of the compound, chemical and physical properties of the resident media (e.g. salinity), and environmental conditions in the overlying air. The physio-chemical properties of PCBs cause them to be somewhat volatile compounds, with calculated half-lives in water in the range of 9-

12 hours (Lyman et al., 1982). Although vapor loss generally decreases with increasing degrees of chlorination, other factors such as the higher solubility of lower-chlorinated blends, and any adsorbants present, greatly influence the ultimate rate of PCB volatilization from soil and surface water. Although the theoretical evaporation rate of PCBs from water has been predicted to be rapid, this may be limited in natural waters due to adsorption of PCBs to sediments (EPA, 1980). Similarly, the vapor loss of Aroclor 1254 has been found to be appreciable from sand, but negligible from strongly-sorbing soil surfaces (Hague, 1980)

The aromatic character of PCBs, their low water solubility and high octanol/water partition coefficient (which represents the tendency of a chemical to partition itself between an organic phase and an aqueous phase), cause them to have a high affinity for soil and sediment particles, especially those high in organic matter. Adsorption of PCBs in most media increases with decreasing water solubility and increases with the organic content of the adsorbant (Griffin and Chian, 1980). Other important factors affecting the adsorption coefficient are the structural characteristics of the compound, pH of the medium, particle size, and ambient temperature. Smaller particles (e.g. clay) show a definite increase in adsorptivity of PCBs. Adsorption reduces the volatilization rate of PCBs from water and soil, and also reduces the tendency of PCBs to migrate in soil and groundwater.

Chemical Transformations

One of the characteristics of PCBs which has made them so popular in industrial use is their extreme chemical stability. They are inert to almost all of the typical reactions which would change their chemical makeup. Except under extreme conditions, PCBs do not undergo oxidation, reduction, addition, elimination, or electrophilic substitution reactions (EPA, 1980).

The only chemical transformation process of significance to PCBs is that of photolysis, whereby chemical decomposition is caused by radiant energy. In aqueous systems, photolysis of PCBs entails the replacement of chlorine with hydroxy groups (EPA, 1980). The rate of photolysis depends both on environmental conditions (e.g. intensity and spectrum of solar radiation, presence or absence of sensitizers) and on compound-specific properties such as the rate and extent of light adsorption and the inherent tendency to undergo photochemical reactions.

In the environment, anaerobic conditions enhance photolysis (EPA, 1980). It has been demonstrated in laboratory work (Callahan et al., 1979; Haque, 1980) that the more highly chlorinated PCB blends are degraded to a greater extent in both air and water than are the less chlorinated species, but whether these results may be extrapolated to natural environmental conditions is open to question. Photolytic dechlorination is also expected to give rise to lower chlorinated isomers, including some which may not have been present in the commmercially manufactured mixtures. Under certain natural

conditions, when the replacement of chlorines by hydroxy groups from water, without the intervention of alkali, occur at the ortho position, photolysis can result in the creation of polychlorinated dibenzofurans.

Environmental Transport

Environmental transport includes both intermedia transfer, (i.e. volatilization from soil to air, deposition from the water column to the sediments) and movement within environmental compartments, such as advective transport in estuarine flow. For chemically unreactive compounds such as PCBs, transport processes are ultimately more important than are transformation processes.

Transport of PCBs in the environment can take place by:

- volatilization from soil and surface water;
- aerial transport via particulates;
- leaching from landfills under certain conditions;
- sediment transport in rivers and estuaries;
- sediment deposition in receiving water bodies;
- uptake, bioaccumulation, and transport by biota.

The transport and transfer of a chemical by each of these pathways may involve several sequential processes, depending on the compartment involved. For an estuary, the principal physical and chemical transport mechanisms would include:

- advective transport of particulate-sorbed PCBs by flowing water;
- mixing in all directions by dispersion;
- vertical transport and deposition to the sediments;

- release from sorbed state on sediments and diffusion into overlying water layers.

Each of these mechanisms has a characteristic rate, diffusion velocity, and tendency to resistance (Haque, 1980). The rates of transport may be calculated from knowledge of the physicochemical properties of PCBS, and the appropriate data on atmospheric conditions, particulate transport, hydraulic dispersion, bottom sedimentation rates, and biodegradation rates. Since PCBs have a strong tendency to adsorb onto particulate matter, they can be assumed, as a crude model, to move in the same manner as sediments or atmospheric particulate matter (Steen et al., 1978). However, the dynamics of such properties as sorption and desorption of PCBs from particulates are not well understood (Lyman et al., 1982). In addition, rates of flux, including volatilization, leaching in unsaturated (with water) soil, biodegradation in natural conditions, and diffusion through stratified water layers are very difficult to quantify for any compound, and are virtually unknown for PCBs.

The principal transport pathways of PCBs in the environment are illustrated in Figure 1, and summarized below.

Transport in Air. Volatilized PCBs may be adsorbed on particulate matter, transported by prevailing winds, and deposited on land or water by wet and dry deposition of particulate and vapor phase PCBs. The initial volatilization is highly dependent on the specific isomer and the availability of sorption sites in the resident media.

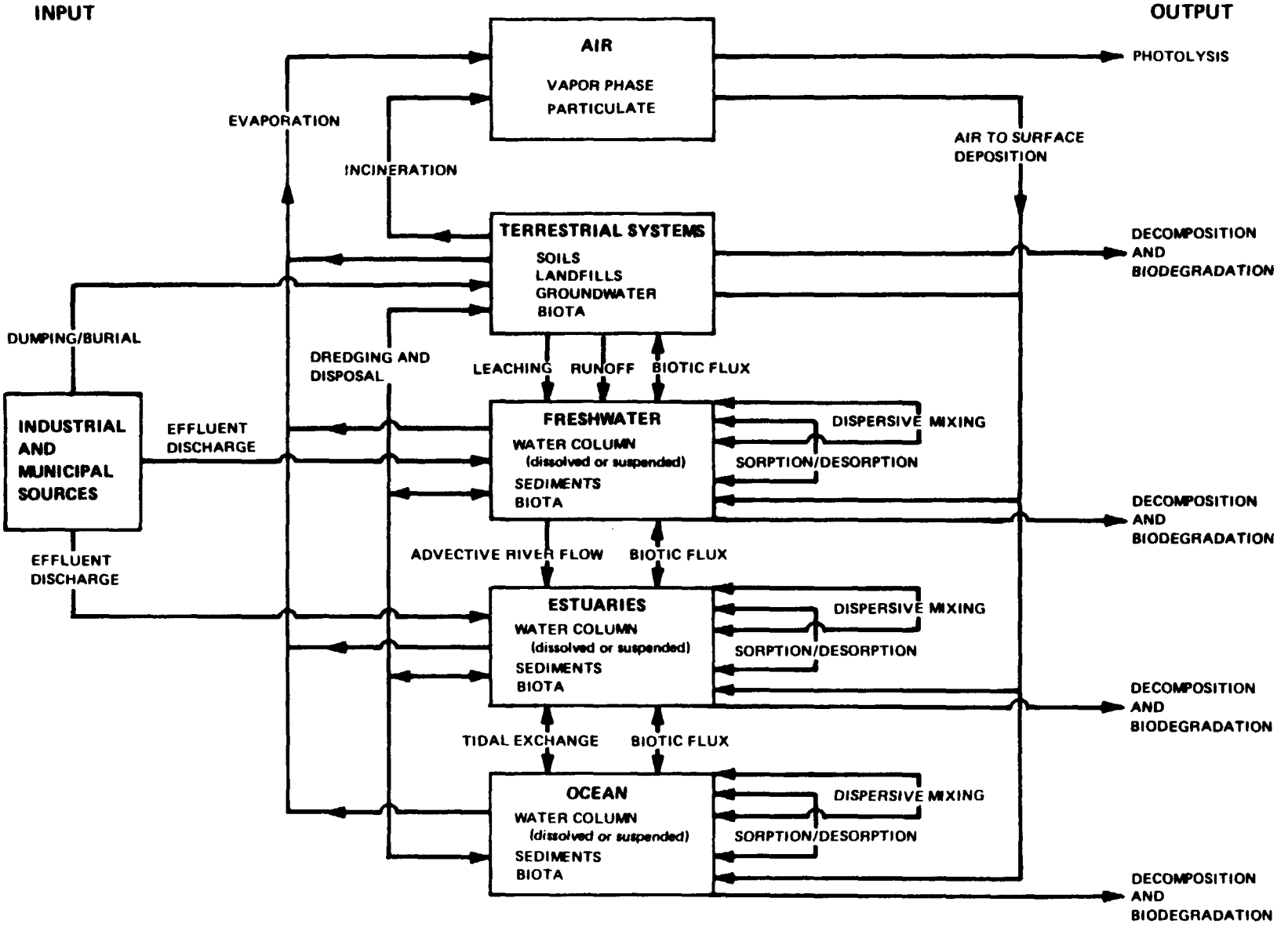

FIG. 1 PCB ENVIRONMENTAL TRANSPORT PATHWAYS

Eisenreich et al. (1980) identified airborne transport and deposition as the major source of PCB input to the Great Lakes, and indicated that this pathway plays a major role in the worldwide distribution of PCBs. Bidleman et al. (1977) estimated the maximum vapor, particle and rain fluxes of PCBs to the Western North Atlantic to be 1.4 $g/km^2/yr$.

Ambient air can also act as a transport route for the byproducts of PCB incineration. Rappe et al. (1979) found that the pyrolysis of PCBs yielded approximately 30 major and more than 30 minor polychlorinated dibenzofurans. One of the major constituents was 2,3,7,8 - tetrachlorinated dibenzofuran, the most toxic of this group of compounds. It is evident, therefore, that, uncontrolled incineration of PCBs can be an important environmental source of highly toxic dibenzofurans.

Transport in Groundwater. Experimental evidence, both laboratory and site data, show that the mobility of PCBs in landfill leachate is very low to negligible, due to strong sorption to organic-rich soils (Griffin and Chian, 1980). If landfilled PCBs were to come in contact with groundwater high in organic content, such as seepage from a pond or a wetland, migration of PCBs might be more significant. Likewise, the absence of suitable soil surfaces for adsorption might increase the likelihood of groundwater transport of PCBs.

Transport in Surface Water. When introduced to surface water, PCBs are adsorbed to a great extent by waterborne particulates, transported with flowing water, and diffused into

the sediments. Some desorption from the sediments may occur, particularly in areas of high concentrations, but the dynamics of this process are not well quantified at present (Haque, 1980).

Because of the high affinity of PCBs for particulate matter, and other fate properties, the sediments in surface water bodies are considered a sink for PCBs (Doskey and Andren, 1981; Nisbet and Sarofim, 1982). In areas of high concentrations, PCBs may be desorbed from the soil or sediments to pore water or the water column, respectively, and thus constitute a continuing sources of PCBs to the aqueous environment (Eisenreich, 1980). In comprehensive studies of PCB dynamics in a pond system it was found that the sediments accumulated PCBs and released them slowly over a period of several years, at a rate largely controlled by the overlying water, in which PCB residence time was only a few days with resultant volatilization (Nisbet and Sarofim, 1972). A study in the Hudson River, north of Albany, N.Y., revealed that PCBs from bottom sediments were released to the river water at a constant rate during low to moderate river flow, but rates of release were accelerated with sediment resuspension during flood flows. It was estimated that this sediment PCB reservoir is sufficient to maintain the current level of water contamination in the Hudson River for approximately one century (Turk, 1980). Similarly, Eisenreich (1980) estimated that PCBs in surficial Lake Superior sediments will be available for biological recycling for the next 30 to 50 years.

Given this potentially large PCB reservoir existing in the bottom sediments of a water body, and since PCBs exhibit a high affinity for soil and sediment particles (especially small and/or organic particles), sediment transport and dynamics represent the major pathway for PCBs an estuarine environment. In a modeling effort of PCB fate in the estuarine portion of the Hudson River System, Thomann et al. (1980) determined that the total PCB concentration in the sediments was partitioned as 55 percent in organic particulates, 20 percent in inorganic particles, and 25 percent in dissolved form. Similar work in the Great Lakes failed to demonstrate a clear correlation between sediment PCB concentration and either sediment texture, organic carbon content, or redox potential (Glooschenko et al., 1976).

Due to sedimentation, differential settling velocities, and possible stratification, the transport of pollutants adsorbed in suspended solids does not adhere to the often-made assumption that the pollutants move in the same manner as the water column. Bottom sediments can also be resuspended through the shearing action of the overlying water, and through the action of benthic organisms that inhabit the upper layers of the bottom sediments; a process known as bioturbation. Further, the transport of PCBs cannot be fully predicted by sediment transport dynamics alone (Nisbet and Sarofim, 1972). The suspended materials of specific relevance to PCB transport do not necessarily act as discrete particles, the settling velocity of which are described by Stoke's law. Rather, these solids

coalesce and flocculate, and therefore require direct settling analysis to determine the empirical settling rates in any specific location. In addition, the sorption and exchange dynamics of PCBs between the water column and suspended solids are not easily quantified and are very site specific.

Studies of contaminated rivers and estuaries demonstrate that hydrography plays an important role in the distribution of PCBs. Downstream transport from the river to its estuary was documented for the Hudson River, New York (Bopp et al., 1981) and the Escambia River, Florida (Nimmo et al., 1971). In the salt-wedge type estuary of the Duwamish River, upstream mobilization by the more dense (saline) bottom water was well documented by Pavlon and Hom, (1979) and Pavlon & Dexter, (1979). PCBs are distributed throughout Raritan Bay (New Jersey) and the Lower New York Bay complex (Stainken and Rollwagen, 1979) as they are throughout Escambia Bay, Florida (Nimmo et al., 1971) due to estuarine and riverine hydrography.

Generally, the lower chlorinated PCB blends are affected by sediment transport and other interactions between different elements of the aqueous environment, and therefore more subject to movement within an estuary (Nisbet and Sarofim, 1972).

Biological Processes Relevant to PCBs

Biological processes which can affect the fate and transport of toxic substances in the environment include biodegradation, bioconcentration (bioaccumulation), trophic transfer, and migration. Biodegradation refers to those metabolic processes by or in an organism which result in a breakdown in the chemical makeup of the contaminant. Bioconcentration reflects the accumulation of the substance within an organism. Trophic transfer refers to the passage of the substance in successive levels of the food chain, and migration refers to the spatial movement of the substance in conjunction with the movment of an individual organism. Biodegradation is the only biotransformation process relevant to PCBs, the remainder of these processes are biotransport processes.

The chemical characteristics of PCBs which are most significant to these biological processes are their low water solubility, high lipid solubility, affinity for organic particles, and extreme chemical stability. As a group, PCBs are recalcitrant, (i.e. they resist biodegradation), and are able to be bioconcentrated. Due to their persistence in the environment, they can also exhibit trophic magnification; increase in organismal concentration with trophic transfer.

There is a large volume of literature available on the presence of PCBs in biological systems. Tables 2 through 15

TABLE 2. BIOCONCENTRATION AND EFFECTS OF PCBs IN ESTUARINE PRIMARY PRODUCERS

	Exposure Conditions						Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF [1]	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
phytoplankton	water	PCB [2]	7	1.3	St George Sound	1970-71					Inhibited carbon uptake					84
phytoplankton	water	PCB [3]	30	1.3	St George Sound	1970-71					LC_{50}					84
phytoplankton	water	1242	1-2	1.3	St George Sound	1970-71					Toxic					84
phytoplankton	water	1242	6.5	1.3	St George Sound	1970-71					Lethal					84
phytoplankton	water	1254	1-2	1.3	St George Sound	1970-71					Toxic					84
phytoplankton	water	1254	15	1.3	St George Sound	1970-71					Lethal					84
Dunaliella sp. Green flagelate	water	PCB	5 or 10	2	Long Island	1977		150	100-200 (lipid)	20,000	Suppressed growth rate and photosynthesis				Steady state	
Chlorella pyrenoidosa Green flagellate	water	PCB	10	.04	Lab			50	32-70 (lipid)	5,000	Inhibited growth and productivity					139
Chorella pyrenoidosa Green flagellate (dead)	water	TCB [4] HCB	10	.04	Lab			110	62-156 (lipid)	11,000					Bioconcentrated more PCB than cells	139

1. Bioconcentration factor.
2. 31% Cl by weight.
3. 31.8% Cl by weight.
4. TCB, Tetrachlorobiphenyl
   HCB, Hexachlorobiphenyl.

TABLE 2 (Continued). BIOCONCENTRATION AND EFFECTS OF PCBs IN ESTUARINE PRIMARY PRODUCERS

	Exposure Conditions						Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
Diatoms	water	1254	5	2	Long Island Sound	1977					Lethal					10
Diatoms	water	1254	0.5	2	Long Island Sound	1977					Altered species diversity and size					10
Diatoms	water	1254	5	1	Long Island Sound						Inhibited chlorophyll A, 3-4 days					100
Diatoms	water	1254	10	5	Long Island Sound						Suppressed growth, 3.5 days				Particles >9 um most sensitive	100
Skeletonema costatum diatom	water	1254	7.5	5	Long Island Sound	1977					Inhibited growth				Steady state	10
Skeletonema costatum diatom	water	1254	1	7	Long Island Sound						Suppressed growth, 3-4 days				Recovered from suspension of growth	100
Rhizosolenia fragilissima diatom	water	1254	10	5	Long Island Sound						Crumpled cytoplasm, misshapen nucleii					100
Cylindrotheca closterium diatom	water	1242	100	1	St George Sound	1970-71		100 (lipid)		1,000	Inhibited growth				Affected carbon uptake	84

TABLE 3. BIOCONCENTRATION AND EFFECTS OF PCBs IN MARINE PRIMARY PRODUCERS

Organism	Exposure Conditions: Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Uptake: Organ	Mean (ppm)	Range (ppm)	BCF	Elimination: Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
Dunaliella tertiolecta Green flagellate	water	PCB	1-10	4	F/2 medium						Increased competitive success				Mixed culture. More sensative than pure	86
Dunaliella tertiolecta Grenn flagellate	water carrier	PCB	1,000	6 10	F/2 medium											85
Dunaliella tertiolecta Green flagellate	water	1254	8.1×10^{-3}	5	medium	1976					Increased competitive success				Steady state reached	121
Dunaliella sp. Grenn flagellate	water	1254	2.7×10^{-3}	5	medium	1976		0.25	0.12-0.38 (dry)		None				Steady state reached	121
Dunaliella tertiolecta Green flagellate	water	PCB	11-25	4	F/2 medium						None				Pure culture	86
Chorella pyrenoidosa Green flagellate	water	PCB	5;10	2	Long Island Sound	1977		120 (lipid)	80-160	16000 (sorption)	Altered species diversity and size				Steady state reached	10
Thallasiosira pseudonana centric diatom	water	1254	1	14	F/2 medium	1976					Diminished competitive success				Steady state reached	121
Thallasiosira pseudonana centric diatom	water carrier	PCB	25	4							Inhibited growth				Pure culture	86
Thallasiosira pseudonana centric diatom	water, carrier	PCB	25-100	10	F/2 medium						Decreased growth					85

TABLE 3 (Continued). BIOCONCENTRATION AND EFFECTS OF PCBs IN MARINE PRIMARY PRODUCERS

	Exposure Conditions						Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
Thalassiosira pseudonana centric diatom	water	1254	10	5	F/2 33 ppt						Diminished growth				From Sargasso Sea	35
Thalassiosira pseudonana centric diatom	water	PCB	10	2	F/2 33 ppt						Diminished growth				Carbon rate diminished by 48%	34
Skeletonema costatum diatom	water, carrier	PCB	10	6	F/2						Some inhibition of of growth					85
Skeletonema costatum diatom	water	PCB	10	2	F/2 33 ppt						Lethal				Carbon rate diminished by 84%	34
Coccolithus huxleyi coccolithopore	water	PCB	10	2	F/2 33 ppt						None				Control	34

TABLE 4. BIOCONCENTRATION AND EFFECTS OF PCBs IN FRESHWATER PRIMARY CONSUMERS

	Exposure Conditions						Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
invertebrates	water	1254		short term						160 - 6,300						115
Daphnia sp. water flea, adult	water	1248	5								Inhibited reproduction					88
Daphnia magna water flea, adult	water	1254	1.1	4			whole	52		47,000						115
Gammarus pseudolimnaeus scud, adult	water	1248	52	4							LC_{50}					91
Gammarus pseudolimnaeus scud, adult	water	1254	1.6	7-21			whole	43		27,000					Steady state	115
Gammarus pseudolimnaeus scud, adult	water	1254	2,400	4							LC_{50}					91
Palaemonetes kadiakensis glass shrimp, adult	water	1254	1.3	21			whole	21.6		16,600						115
Palaemonetes kadiakensis glass shrimp, adult	water	1254	3,000	7							LC_{50}					91
Pteronarcys dorsata stonefly, larva	water	1254	2.8	7-21			whole	7.8		2,800					Steady state	115
Culex tarsialis mosquito, larva	water	1254	1.5	7			whole	30		20,000					Steady state	115

TABLE 5. BIOCONCENTRATION AND EFFECTS OF PCBs IN FRESHWATER SECONDARY CONSUMERS

Organism	Exposure Conditions: Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Uptake: Organ	Mean (ppm)	Range (ppm)	BCF	Elimination: Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
Orconectes nais crayfish, adult	water	1254	1.2	21			whole	6.1		5,100						115
Chaoborus punctipennis midge, larva	water	1254	1.3	14			whole	32.2		24,800						115
Carydalys cornutus dobsonfly, larva	water	1254	1.1	21			whole	7.5		6,800					Steady state	115
Anguilla rostrata American eel, adult		PCB			Canadian freshwater	1970	whole	0.71	0.36-1.01							165
Anguilia rostrata American eel, adult		PCBs			Canadian freshwater	1970	liver	0.57								165
Phoxinus phoxinus European dace, adult-egg		C50[a]					ovary	15			Significant reduction in hatch					5
Pimephales promelas fathead minnow, adult	water	1016	8.7	32	25° C		whole	370		42,500						148
Pimephales promelas fathead minnow, embryo-early juvenile	water	1242	5.4 - 15.0	90							Threshold mortality (MATC)				No difference if parents were exposed or not	89

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TABLE 5 (Continued). BIOCONCENTRATION AND EFFECTS OF PCBs IN FRESHWATER SECONDARY CONSUMERS

	Exposure Conditions					Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
Pimephales promelas fathead minnow, adult	water	1242					whole	92			~50% reduction in reproductive success					89
Pimephales promelas fathead minnow, embryo-early juvenile	water	1248	1.1 - 3.0	60							Threshold mortality (MATC)				Most sensitive stage	23
Pimephales promelas fathead minnow, adult	water	1248	4.0	32	25° C		whole	282		70,500						148
Pimephales promelas fathead minnow, embryo-early juvenile	water	1254	1.8 - 4.6	90							Threshold morality (MATC)				No difference if parents were exposed or not	89
Pimephales promelas fathead minnow, adult	water	1254	4.3	32	25° C		whole	430		100,000						148
Pimephales promelas fathead minnow, adult	water	1260	1.0	32	25° C		whole	194		194,000						148
Pimephales promelas fathead minnow	water	1260	2.1 - 4.0	60							Threshold mortality (MATC)					23
Jordanella floridae flagfish, adult	water	1242					whole	92			~50% reduction in reproductive success					89

TABLE 6. BIOCONCENTRATION AND EFFECTS OF PCBs IN FRESHWATER TERTIARY CONSUMERS

Organism	Exposure Conditions: Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Uptake: Organ	Mean (ppm)	Range (ppm)	BCF	Elimination: Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
Salmo trutta brown trout	water	PCB	0.005		Lake Michigan		whole	5								23
Salmo trutta brown trout	water, food	PCBs	0.005 2.5	57	April-June		whole	0.5							Steady state	23
Salmo gairdneri rainbow trout, adult-eggs		PCB			Hatchery		ovary	2.8			High mortality of eggs					54
Salmo salar Atlantic salmon, egg-fry		PCB					eggs	6 lipid			No harm to eggs and fry				Anadromous	166
Salmo salar Atlantic salmon, egg		PCB					eggs	17			50% mortality				Anadromous	63
Salmo salar Atlantic salmon, egg		PCB					egg		7.7-3.4 lipid		16-100%				Anadromous	61
Monore saxatilis striped bass, larva	water, acetone	1254	1.36	1.0	20.5-25.5° C 2-4%		whole	0.0051 dry			2.0		<1		Anadromous	18
Monore saxatilis striped bass, larva	water	1254	1.36-0.544 (0.952)	2.0	20.5-25.5° C 2-4%		whole	0.0059 dry			2.0	0.0043	18		Steady state, dry used 60% of PCB available, anadromous	18

TABLE 7. BIOCONCENTRATION AND EFFECTS OF PCBs IN ESTUARINE PRIMARY CONSUMERS

	Exposure Conditions						Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
Crassostrea virginica American oyster	water	1016	10								50% mortality					26
Crassostrea virginica American oyster	water	1242	100								Toxic					26
Crassostrea virginica American oyster, young adult	water	1254	0.01	372							No mortality					26
Crassostrea virginica American oyster	water	1254	1	168				100		100,000	No decreased growth					26
Crassostrea virginica American oyster, young adult	water	1254	4	168							Decreased growth					26
Crassostrea virginica American oyster	water	1254	4	14							Decreased growth					72
Crassostrea virginica American oyster	water	1254	5								Tissue alterations					26
Crassostrea virginica American oyster, small adult	water, acetone	1254	1	4.0	19° C, 31 ppt					>8,000	19% reduction in growth	4	8.1			26

TABLE 7 (Continued). BIOCONCENTRATION AND EFFECTS OF PCBs IN ESTUARINE PRIMARY CONSUMERS

	Exposure Conditions						Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
Crassostrea virginica American oyster, small adult	water, acetone	1254	10	4	19° C, 31 ppt					>3,300	41% reduction in growth	4 d	33.0			26
Crassostrea virginica American oyster, small adult	water, acetone	1254	100	4	19° C, 31 ppt						Complete inhibition of growth	21			Growth resumed	26
Crassostrea virginica American oyster	water	1254	1	30						101,000						26
Crassaostrea virginica American oyster	water	1254								101,000 (max)						72
Crassostrea virginica American oyster	water	1254								165,000 (max)						26
Crassostrea virginica American oyster, adult	water, sediment	1254	ND <310		Escambia Bay summer, fall	1971	whole	0.015				During spawning	0.002	87	Highest concentration in upstream sediments	162
Crassotrea virginica American oyster, adult	water, sediment	1254	ND <10		Escambia Bay, summer, fall	1972	whole	0.011				During spawning	0.002	82		162
Crassostrea virginica American oyster, adult	water, sediment	1254	ND ND		Escambia Bay	1973	whole	0.005				During spawning	0.001	80	Steady state from upstream	162

TABLE 7 (Continued). BIOCONCENTRATION AND EFFECTS OF PCBS IN ESTUARINE PRIMARY CONSUMERS

	Exposure Conditions						Uptake				Elimination					
Organism	Source	Isomer or Arocolor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF [1]	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
Crassostrea virginica American oyster	water	1,260	10								44% reduction in growth					26
Crassostrea virginica American oyster	water	1,260	100								52% reduction in growth					26
Mytilus californianus mussel, adult	sediment (suspended)	PCB	1,300	25	12° C, 33 ppt		whole	$<10^{-7}$							Natural sediment	104
Nereis diversicolor, clam worm	water	PCB					whole	15% body burden		800					Not from interstitial water	36
	sediment	PCB					whole	85% body burden		3.5						
amphipod	water	1254	10	30							Lethal					26
Palaemonetes pugio, glass shrimp	water	1016	10								LC_{50}					26
Palaemonetes pugio, glass shrimp	water	1254	4	16							Lethal					26
Palaemonetes pugio, glass shrimp	water	1254	7.0							3,200-11,000						26
Palaemonetes pugio, glass shrimp	water	1254								2,600 (max)						94
Crangon septemspinosa, sand shrimp, adult	sediment	1242	>800 dry								Lethal threshold					167

TABLE 7 (Continued). BIOCONCENTRATION AND EFFECTS OF PCBs IN ESTUARINE PRIMARY CONSUMERS

	Exposure Conditions					Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
Crangon septemspinosa, sand shrimp, adult	sediment	1254	>2,500 dry								Lethal threshold					167
commercial shrimp	water	1254	<1	4							LC_{50}					26
Penaeus spp. shrimp	water	1254	1	>14							Toxic increased sensitivity to salinity stress					93
Penaeus spp. shrimp, adult	water	1254			Escambia Bay	1969	whole		0-14							92
Penaeus spp. shrimp, adult	water	1254			Escambia Bay	1969	hepatopancreas		0.6-120							92
Penaeus aztecus brown shrimp	water	1016	10								LC_{50}					26
Penaeus duorarum pink shrimp, juvenile	water	1254	1	2	16° C, 26 ppt		whole	0.14		140	No mortality					26
Penaeus duorarum pink shrimp, juvenile	water	1254	3	15							50% mortality					26
Penaeus duorarum pink shrimp, juvenile	water, acetone	1254	3.5-4.2	10	17° C, 28 ppt	July-Aug.					No mortality					26
Penaeus duorarum pink shrimp, juvenile	water, acetone	1254	3.5-4.2	10-20	27° C	July-Aug.	whole (dead)	16		4,156					No symptoms of pesticide poisoning	26

TABLE 7 (Continued). BIOCONCENTRATION AND EFFECTS OF PCBs IN ESTUARINE PRIMARY CONSUMERS

Organism	Exposure Conditions: Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Uptake: Organ	Mean (ppm)	Range (ppm)	BCF	Elimination: Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
Penaeus duorarum pink shrimp, juvenile	water acetone	1254	3.5-4.2	20	27° C 28 ppt July-Aug.		whole (live)	33		8,571	72% mortality					26
Penaeus duorarum pink shrimp, juvenile	water acetone	1254	10	2	16° C, 26 ppt		whole	1.3		130	No mortality					26
Penaeus duorarum pink shrimp, juvenile	water acetone	1254	100	2	16° C, 26 ppt		whole	3.9		3.9	100% mortality					26
Penaeus duorarum pink shrimp, immature	water	1254	940	15							>50% mortality					88
Penaeus duorarum pink shrimp, adult	water	1254	3	35							50% mortality viral infections					26
Penaeus duorarum pink shrimp adult	water	1254	5	20							72% mortality					26
Penaeus duorarum pink shrimp	water	1254	100	22							100% mortality					26
Penaeus duorarum pink shrimp, adult	silt	1254	1,400 dry	30	17° C 27 ppt		hepatopancreas	~0.2							ND uptake in control	93
Penaeus duorarum pink shrimp, adult	silt	1254	2,500 dry	30	17° C, 27 ppt		hepatopancreas	1.1								

TABLE 7 (Continued). BIOCONCENTRATION AND EFFECTS OF PCBs IN ESTUARINE PRIMARY CONSUMERS

Organism	Exposure Conditions: Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Uptake: Organ	Mean (ppm)	Range (ppm)	BCF	Elimination: Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
Penaeus duorarum pink shrimp, adult	silt	1254	4,900	30	17° C, 27 ppt		hepatopancreas	1.3								92
Penaeus duorarum pink shrimp adult	silt, water	1254	30,000 dry 0.5	30	17° C, 27 ppt		hepatopancreas	6.1								92
Penaeus duorarum pink shrimp, adult	sandy silt	1254	41,000 dry	30	17° C, 27 ppt		hepatopancreas	6.7							ND uptake in control	92
Penaeus duorarum pink shrimp, adult	sandy silt	1254	5,700	30	17° C, 27 ppt		hepatopancreas	9.8								92
Penaeus duorarum pink shrimp, adult	sandy silt, water	1254	61,000 dry 3.5	30	17° C, 27 ppt		hepatopancreas	240								92
Penaeus duorarum pink shrimp	water	1260	100								10% mortality					26
fiddler crab, adult	sand	1,254	<2000 dry	30	13° C, 27 ppt		whole	0.3±0.2							Not continuously covered with water	92
Penaeus duorarum fiddler crab, adult	silt	1254	2,500 dry	30	13° C, 27 ppt		whole	3.2±0.9								92
Penaeus duorarum fiddler crab, adult	silt	1254	4,900 dry	30	13° C, 27 ppt		whole	3.6±0.9								92

TABLE 7 (Continued). BIOCONCENTRATION AND EFFECTS OF PCBs IN ESTUARINE PRIMARY CONSUMERS

	Exposure Conditions						Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
fiddler crab, adult	silt water	1254	30,000 dry, 0.5	30	13° C, 27 ppt		whole	17±9								92
fiddler crab, adult	sandy silt, water	1254	61,000 dry, 3.5	30	13° C, 27 ppt		whole	80±25								92

TABLE 8. BIOCONCENTRATION AND EFFECTS OF PCBs IN ESTUARINE SECONDARY CONSUMERS

	Exposure Conditions						Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
Callinectes sapidus, blue crab, juvenile	water, acetone	1254	3.5 - 4.2	20	28° C 27 ppt Aug. - Sept.		whole	23	18-27	5,974		7.0	22 (10-37)	~4		26
Callinectes sapidus, blue crab, juvenile	water, acetone	1254			28° C 27 ppt Aug. - Sept.		whole	23	18-27			28	11 (3-14)	52		26
Callinectes sapidus, blue crab, adult	water	1254	5	20				8		4,000	not affected					26
fishes	water	1016	28							3,400 (max)					Steady state	47
fishes	water	1254	28							3,700 (max)					Steady state	47
Anguilla rostrata, american eel, small adult (<2.5 lbs.)		PCB			St. Lawrence River	1975	edible	3.0							Catadromous	41
Anguilla rostrata American eel, medium adult (2.5-4.5 lbs.)		PCB			St. Lawrence River	1975	edible	8.2							Catadromous	41
Anguilla rostrata American eel, large adult (>4.5 lbs.)		PCB			St. Lawrence River	1975	edible	12.4							Catadromous	41

TABLE 8 (Continued). BIOCONCENTRATION AND EFFECTS OF PCBs IN ESTUARINE SECONDARY CONSUMERS

Organism	Exposure Conditions: Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Uptake: Organ	Mean (ppm)	Range (ppm)	BCF	Elimination: Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
Fundulus heteroclitus killifish	water	1221	25								85% mortality					26
Cyperinodon variegatus sheepshead minnow, adult-eggs	water	1016	0.3	28			eggs	3		10,000	no effect on fry					46
Cyperinodon variegatus sheepshead minow, adult-eggs	water	1016	3	28			eggs	7		2,333	no effect on fry					46
Cyperinodon variegatus sheepshead minnow	water	1016	≤10	28						2,500-8,100	not affected					26
Cyperinodon variegatus sheepshead minnow	water	1016	32-100	28							died					26
Cyperinodon variegatus sheepshead minnow, fry juvenile, or adult	water	1016	15	>14							lethal					46
Cyperinodon variegatus sheepshead minnow, fry	water	1254	0.1								LC_{50}				Most sensitive estuarine organism tested	26

TABLE 8 (Continued). BIOCONCENTRATION AND EFFECTS OF PCBs IN ESTUARINE SECONDARY CONSUMERS

	Exposure Conditions						Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
Cyperinodon variegatus sheepshead minnow, fry	water	1254	3	<14							lethal					26
Cyperinodon variegatus sheepshead minnow, juvenile	water	1254	0.1	>14							lethal to some					118
Cyperinodon variegatus sheepshead minnow, juvenile	water	1254	5	>14							lethal					118
Cyperinodon variegatus sheepshead minnow, adult-egg	water	1254	0.1	28			eggs	≥5			decreased survival of fry, unaffected adults					45
Lagodon rhomboides, pinfish	water	1016	15	>14							lethal					45
Lagodon rhomboides, pinfish	water	1016	21	42				1.1		11,000-24,000	significant mortality					26
Lagodon rhomboides, pinfish	water	1016	32	42				0.34		11,000-24,000	significant mortality, liver alterations					26
Lagodon rhomboides, pinfish	water	1016	100	4							18% mortality					26

TABLE 8 (Continued). BIOCONCENTRATION AND EFFECTS OF PCBs IN ESTUARINE SECONDARY CONSUMERS

	Exposure Conditions						Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
Lagodon rhomboides, pinfish, juvenile	water	1254	1	2	16° C 26 ppt		whole	0.98		1,000	no mortality					26
Lagodon rhomboides pinfish, juvenile 30 mm SL	water, carrier	1254	5	12	16-22° C 20-32 ppt						50% mortality					44
Lagodon rhomboides, pinfish, juvenile 30 mm SL	water, carrier	1254	5	14	16-22° C 20-32 ppt		whole	14		2,800	66% mortality					44
Lagodon rhomboides, pinfish, juvenile	water	1254	~5	>14							lethal					44
Lagodon rhomboides pinfish, juvenile	water, carrier	1254	5	35	22-32° C 14-34 ppt		whole	109		21,800	41% mortality					44
Lagodon rhomboides pinfish, juvenile	water	1254	10	2	16° C 26 ppt		whole	38		380	no mortality					26
Lagodon rhomboides pinfish, juvenile	water	1254	100	2	16° C 26 ppt		whole	17		170	no mortality					26
Lagodon rhomboides pinfish	water	1260	100								no mortality					26
Leiostomus xanthurus spot, juvenile 40mm SL	water, carrier	1254	1	56	23-32° C 10-34 ppt		whole	27		27,000	1% mortality	84	7.2	73	Steady state	44

TABLE 8 (Continued). BIOCONCENTRATION AND EFFECTS OF PCBS IN ESTUARINE SECONDARY CONSUMERS

	Exposure Conditions						Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
Leiostomus xanthurus spot, juvenile 40mm SL	water, carrier	1254	1	56	23-32° C 10-34 ppt		muscle	6.5		6,500		84	2.0	69	Steady state	44
Leiostomus xanthurus spot, juvenile 40mm SL	water, carrier	1254	1	56	23-32° C 10-34 ppt		liver	83		83,000		84	22	73	Steady state	44
Leiostomus xanthurus spot, juvenile 40mm SL	water, carrier	1254	1	56	23-32° C 10-34 ppt		gills	46		46,000		84	12	74	Steady state	44
Leiostomus xanthurus spot, juvenile 40mm SL	water, carrier	1254	1	56	23-32° C 10-34 ppt		brain	8.3		8,300		84	2.9	65	Steady state	44
Leiostomus xanthurus spot, juvenile 40mm SL	water, carrier	1254	1	56	23-32° C 10-34 ppt		heart	13		13,000		84	2.5	81	Steady state	44
Leiostomus xanthurus spot, juvenile 25mm SL	water, carrier	1254	1	33	14-16° C 16-32 ppt		whole	17		17,000	17% mortality					44
Leiostomus xanthurus spot, juvenile 24mm SL	water, carrier	1254	5	26	8-10° C 20-32 ppt		whole	120		24,000	50% mortality					44
Leiostomus xanthurus spot, juvenile 74mm SL	water, carrier	1254	5	38	28-33° C 23-34 ppt						50% mortality					44

TABLE 8 (Continued). BIOCONCENTRATION AND EFFECTS OF PCBs IN ESTUARINE SECONDARY CONSUMERS

Organism	Exposure Conditions: Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Uptake: Organ	Mean (ppm)	Range (ppm)	BCF	Elimination: Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
Leiostomus xanthurus spot, juvenile 74mm SL	water, carrier	1254	5	45	28-33° C 23-34 ppt		whole	152		30,400	62% mortality					44
Leiostomus xanthurus spot, juvenile	water	1254	5	20-45							lethal					26
Leiostomus xanthurus spot, juvenile	water	1254	~5	>14							lethal					21
Leiostomus xanthurus, spot	water	1254		14-28						37,000						26
Platichthys flesus Baltic flounder, adult-eggs	water	PCB	≤0.14		Baltic Sea		ovary	0.120 0.012, lipid		~50% reduction in hatch					255 ppb=11.6 ppb lipid, fish w/120 ppb had no fat	149

TABLE 9. BIOCONCENTRATION AND EFFECTS OF PCBs IN MARINE SECONDARY CONSUMERS

	Exposure Conditions						Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
Nereis virens clam worm, adult (3 sizes)	water	1254		1.0			whole			50-500				0		80
Homarus americanus American lobster, adult		1242 1254			Frenchmans Bay		muscle	0.10	0.07-0.13							4
Homarus americanus American lobster, adult		1242 1254			Frenchmans Bay		hepato-pancreas	1.6	1.1-2.3							4
Homarus americanus American lobster, adult		1242 1254			Frenchmans Bay		egg mass	4.4	2.8-6.0							4
Homarus americanus American lobster, adult	food	TPCB[1]	600	28->42	10° C		hepato-pancreas	3.1		5.1		42		~100	steady state 10-28% lipid	80
Homarus americanus American lobster,adult	food	TPCB	400	28->42	10° C		hepato-pancreas	4.0		1.0		42		~60	steady state 10-28% lipid	80
Homarus americanus American lobster,adult	food	TPCB	400	42	10° C		tail	0.039		>0.01		42		~80	steady state not reached 0.11-0.44% lipid	80

1. TPCB = tetrachlorobiphenyl

TABLE 9 (Continued). BIOCONCENTRATION AND EFFECTS OF PCBs IN MARINE SECONDARY CONSUMERS

Organism	Exposure Conditions: Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Uptake: Organ	Mean (ppm)	Range (ppm)	BCF	Elimination: Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
Homarus americanus American lobster,adult	food	TPCB	400	42	10°C		claw	0.273		>0.07		42		~80	steady state not reached 0.14-0.72% lipid	80
Homarus americanus American lobster,adult	food	HPCB[1]	550	4->42	10°C		hepato-pancreas	4.0		7.3		42		~100	steady state 10-28% lipid	80
Homarus americanus American lobster,adult	food	HPCB	490	42	10°C		hepato-pancreas	14.2		>2.9		42		~40	steady state not reached 10-28% lipid	80
Homarus americanus American lobster,adult	food	HPCB	490	42	10°C		tail	0.027		>0.006		42		~40	steady state not reached 0.11-0.44% lipid	80
Homarus americanus American lobster,adult	food	HPCB	490	42	10°C		claw	0.123		>0.04		42		~90	steady state not reached 0.14-0.72% lipid	80
Homarus americanus American lobster,adult	intra-venous 0.2 mg/kg	PPCB[2]		-			muscle					<7		50		4
Homarus americanus American lobster,adult	intra-venous 0.2 mg/kg	PPCB		-			hepato-pancreas					45		50		4

1. HPCB = hexachlorobiphenyl
2. PPCB = pentachlorobiphenyl

TABLE 9 (Continued). BIOCONCENTRATION AND EFFECTS OF PCBs IN MARINE SECONDARY CONSUMERS

	Exposure Conditions					Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
Homarus americanus American lobster, adult	intravenous 0.2 mg/kg	PPCB		-			egg mass					39		50		4
Microdadus tomcod tomcod, adult		1016 1254			Hudson River Estuary Jan-Feb	1978	whole w/o liver & gonad	0.2	0.01-0.7						lower conc. in larger animals	65
Microdadus tomcod tomcod, adult		1016 1254			Hudson River Estuary	1978	liver	37	11-98						liver abnormality NOT correlated with PCB	65
Microdadus tomcod tomcod, adult		1016 1254			Hudson River Estuary	1987	gonad	1.2	0.01-7.4							65
Microdadus tomcod tomcod, adult		1016 1242			Hudson River Estuary	1978	whole	6.5								124
Microdadus tomcod tomcod, adult		1016 1254			Hudson River Estuary	1978	muscle	1.5								124
Microdadus tomcod tomcod, adult		1254			Hudson River Estuary	1978	whole	7.7								124
Microdadus tomcod tomcod, adult		1254			Hudson River Estuary	1978	muscle	1.3								124

TABLE 9 (Continued). BIOCONCENTRATION AND EFFECTS OF PCBs IN MARINE SECONDARY CONSUMERS

	Exposure Conditions						Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
Gadus morhua cod,adult	food	1254	1,000-50,000	92			livers		3.5-3.7%							146
Gadus morhu cod,adult	food	1254	1,000-50,000	92			testes		0.05-5.3							146
fish	water	1254								61,000						77
fish	food									1-7						77,37

TABLE 10. BIOCONCENTRATION AND EFFECTS OF PCBs IN MARINE TERTIARY CONSUMERS

	Exposure Conditions					Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
Squalus acanthus spiny dogfish, adult		1242 1254			Frenchmans Bay, ME		muscle	0.4								4
Squalus canthus spiny dogfish, adult		1242 1254			Frenchmans Bay, ME		liver	1.9								4
Squalus acanthus spiny dogfish, adult		1242 1254			Frenchmans Bay, ME		kidney	~0.2								4
Squalus acanthus spiny dogfish, adult	intravenous 0.2 mg/kg	PPCB[1]					liver					7		11 (±11)		4
Squalus acanthus spiny dogfish, adult	intravenous 0.2 mg/kg	PPCB					kidney					7		94		4
Squalus acanthus spiny dogfish, adult	intravenous 0.2 mg/kg	PPCB					heart					7		99		4

1. PPCB = pentachlorobiphenyl

TABLE 11. BIOCONCENTRATION AND EFFECTS OF PCBs IN AVIAN PRIMARY CONSUMERS

	Exposure Conditions						Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
swan		PCB			Denmark	1972		2.2							industrial area	156
mallards		PCB	$4x10^4$	49							low egg production and hatchability					156
mallards		1254	single dose								egg shell thinning				short term	156
black duck					Northeast USA and Canada	1971		3.3	1-6.9							156
pheasants		1254	50 mg	192							low egg production and hatchability					156
chicken					Bay of Fundy	1974		<0.010								156
chicken, egg-chick	injected	1242					yolk				beak abnormalities					156
chicken, hens	food	1232 and 1254	$2x10^4$								teratogenic					156
ring doves		1254	$1x10^4$	35							none					156
ring doves		1254									low hatching rate in second generation				2 generations	156
finches		PCB			Lab		liver	345			failure of limb coordination				50% mortality	15

TABLE 12. BIOCONCENTRATION AND EFFECTS OF PCBs IN AVIAN SECONDARY CONSUMERS

	Exposure Conditions					Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
eider		PCB			Denmark	1970-1972		35 14								156
ducks, purple sandpipers		PCB			Denmark West Coast of Greenland	1974	adipose	2.2	1.2-3.3							156
woodcock		PCB			USA (11 states)	1973	wings	6.5	4.27-8.63						whole bird, extracted lipid	156
starling		PCB			Norway	1970	breast muscle	0.014								156

TABLE 13. BIOCONCENTRATION AND EFFECTS OF PCBs IN AVIAN TERTIARY CONSUMERS

	Exposure Conditions					Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
birds, adult		PCB			North Atlantic		liver fat, liver	24 535 311			failure of limb coordination, convulsions				wasted and underweight	15
19 native bird species, egg		PCB			Germany	1974-1976		425	2.0-847							156
terrestrial and aquatic birds		PCB			Spain	1974		5.6	5-6.2							156
carnivorous birds		PCB			Norway	1972	breast muscle	3.0								156
terrestrial predatory birds		PCB			Denmark & Greenland	1971	liver	137	1.3-272							156
Bird feeding raptors		PCB			England	1978	liver	70								156
freshwater fish-eating birds		PCB			England	1968	liver	900								156
fish-eating birds, egg		PCB			Upper Great Lake States	1973		339.7								156
fish-eating birds, egg		PCB			Louisiana	1973		35								156
Podiceps grisegna red-necked grebe egg		PCB			Upper Great Lake States	1973		744.6								156

TABLE 13. BIOCONCENTRATION AND EFFECTS OF PCBs IN AVIAN TERTIARY CONSUMERS

Organism	Exposure Conditions: Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Uptake: Organ	Mean (ppm)	Range (ppm)	BCF	Elimination: Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
pelicans		PCB			South Dakota	1973	adipose		2.24							156
Pelecanus occidentalis brown pelican, egg		PCB			USA	1971		6	<1.0-11							156
Pelecanus occidentalis brown pelican, egg		PCB			South Carolina	1970		6.1	5-74.5							156
		PCB				1971		5.2	3.9-70.4							156
		PCB				1971		6.5	1.5-36.5							156
		PCB				1972		7.5	2.6-32.3							156
		PCB				1973		4.7	0.9-19.3							156
Morus bassanus gannets		PCB			England E. & W. Coasts	1973	liver	7,145	4,720-9,570							156
Phalacrocorax auritus double-crested comorant					Canada, New Brunswick	1972		45.6								156
Phalacrocorax auritus double-crested comorant		PCB			Canada USA	1972	breast muscle	3.38								156
cormorants		PCB			Denmark West Coast of Greenland	1974		31.7	26.30 37.10							156
cormorant		PCB			The Netherlands	1972	brain liver	190 319							dead	156
cormorant		PCB			The Netherlands	1973	carcasses brain	0.75 0.69	0.50-1						dead	156

TABLE 13 (Continued). BIOCONCENTRATION AND EFFECTS OF PCBs ON AVIAN TERTIARY CONSUMERS

	Exposure Conditions					Uptake				Elimination				
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
Mergus merganser common merganser egg		PCB			Upper Great Lake States	1973		260.2						53		
Mergus sp. red crested merganser, egg		PCB			Upper Great Lake States	1973		489.0								156
Haliaectus leucocephalus bald eagle					Northeastern USA and Ontario	1966-1973		434								156
Haliaectus leucocephalus bald eagle		PCB			USA (17 States)	1971 1971 1972 1972	carcasses brain carcasses brain	145 75 600 95	.30-290 .10-150 .60-1200 .65-190							156
Haliaectus leucocephalus bald eagle		PCB			USA	1972	brain	235								156
Haliaectus leucocephalus bald eagle, egg		PCB			Kodiak, Alaska	1969		2.2								156
		PCB			Admiral Isle	1970		1.1								156
		PCB			Maine	1969		9.9								156
Haliaectus leucocephalus bald eagle, egg		PCB			Florida	1969		12.2								156
		PCB			Michigan	1969		27.7								156
		PCB			Minnesota	1969-70		7.7								156
white-tailed eagle, adult		PCB			USA	1970		14,000								156
white-tailed eagle		PCB			Germany	1972		52	6.1-97							156

TABLE 13 (Continued). BIOCONCENTRATION AND EFFECTS OF PCBS IN AVIAN TERTIARY CONSUMERS

	Exposure Conditions					Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
white tailed eagle, adult		PCB			Sweden		muscle brain	215 29	190-240						population on decline	60
Pandion haliactus osprey		PCB			Finland	1972		25								156
Falco peregrinus peregrine falcon		PCB			USA	1970		2,000								156
Falco peregrinus peregrine falcon					USA			2,000								156
Falco peregrinus peregrine falcon, young		PCB			Western shore of USA	1970	adipose tissue		52.5							156
Falco columbiarus merlin, adult		PCB			Lake Michigan	1968-1969		196								156
Falco columbiaris merlin, immature		PCB			Lake Michigan	1968-1969		28.6								156
Falco sparverius sparrow hawk		PCB			The Netherlands	1969-1971		47								156
heron, adult					USA			900								156

TABLE 13 (Continued). BIOCONCENTRATION AND EFFECTS OF PCBs IN AVIAN TERTIARY CONSUMERS

	Exposure Conditions					Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
gulls and skuas, large		PCB			Scotland-Arctic	1972	muscle and liver		535							156
common gull		PCB			Norway	1971		0.4	trace-0.8							156
gull					New Brunswick	1972		7.4								156
gull, egg		PCB			France	1973		0.8								156
herring gull		PCB			Norway	1971		19.1	0.2-38							156
herring gull					Bay of Fundy	1972		0.1								156
herring gulls		PCB			Bay of Fundy	1972	adipose		1.4							156
herring gull, egg		PCB			Upper Great Lake States	1973		2,224								156
herring gull, egg		PCB			USA	1973		300								156
terns		PCB			Long Island Sound	1971	Breast muscle	90	5-175							156

TABLE 13 (Continued). BIOCONCENTRATION AND EFFECTS OF PCBs IN AVIAN TERTIARY CONSUMERS

	Exposure Conditions					Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
terns, young		PCB			Great Gull Island	1969-1970	breast muscle	25								156
Uria aalge common murre		PCB			Oregon Coast	1969	brain	4,000							dead birds	156
Uria aalge common murre, egg		PCB			Farallon Island	1971	lipids	168								156
Cepphus grylle guillemot		PCB			England, Irish Sea	1973 1973 1973	carcasses liver carcasses liver	3 50 1.0 0.53							dead shot	156 156
Cepphus grylle guillemot	PCB				Sweden, Baltic	1969		16								156
Cepphus grylle guillemot		PCB			Denmark, West Coast of Greenland	1974		11.1	10.10-12.9							156
Cepphus grylle guillemot, egg		PCB			Baltic Sea		fat	250	140-360							60
Cepphus grylle guilemot, egg		PCB			Sweden			16	7.9-21							60
Eagle owls		PCB			Sweden SE Coast	1973 1973	brain breast muscle	260 110							Found dead	156

TABLE 14. BIOCONCENTRATION AND EFFECTS OF PCBs ON TERRESTRIAL PRIMARY CONSUMERS

	Exposure Conditions					Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
herbivorous mammals					Sweden	1973		0.1								156
hares					Germany	1974	adipose	0.22							20 out of 22 samples	156
rabbit		1254	0.0125	28							abortions, fetotoxicity					156
cows, nursing					USA	1977		5.8								156
cows, newborn					USA	1977	adipose	5.5								156
cows, 2 months					USA	1977	adipose	33								156
cows, 2 months					USA	1977	plasma	3.4								156

TABLE 15. BIOCONCENTRATION AND EFFECTS OF PCBs IN TERRESTRIAL AND TERTIARY CONSUMERS

	Exposure Conditions						Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
mink	food	1254	5,000								reproductive failure					156
minks (found dead)		PCB			New England	1977									79 x amount detected in minks in 1974	156
American mink		PCB			Sweden	1973	muscle adipose	0.58 45								156
fox		PCB			Germany	1974	adipose	2.5							1 out of 5 samples	156
seal, adult		PCB			Baltic		fat	310								60
seal, pup		PCB			Sea		fat	65								60
seal, adult		PCB					milk	30								60
sea lion		PCB			South California						high rate of premature births				naturally exposed	156
monkeys		1248	2,500								lower fertility lower birth weight					156
macaca mulatta monkey		1248	$1x10^5$-$3x10^5$	.002							hair loss facial edema					156
macaca mulatta monkey		1248	$2.5x10^3$								facial edema acne developed 1-2 mos				lesions severe in females, moderate in males	156
rhesus monkey		1248	$3x10^5$								tumor of stomach lining					156
rhesus monkey		1248	$2.5x10^4$								hair loss, acne after 1 month					156

TABLE 15 (Continued). BIOCONCENTRATION AND EFFECTS OF PCBs IN TERRESTRIAL TERTIARY CONSUMERS

	Exposure Conditions					Uptake				Elimination					
Organism	Source	Isomer or Aroclor	Concentration (ppb)	Duration (days)	Location, conditions	Year	Organ	Mean (ppm)	Range (ppm)	BCF	Effects	Duration (days)	Terminal concentration (ppm)	% Decrease	Comments	Ref.
rhesus monkey		C30[1]	4,000	28							central nervous system degeneration					156
rhesus monkey		C30									degenerative changes in liver				dose dependent	156
rhesus monkey, lactating		C30									degenerative changes in liver of infant				slight to moderate	156

1. C30 = Colphen A 30

summarize data in the literature relating to the bioaccumulation and effects of PCBs. The data in these tables are arranged by habitat and trophic level.

Biodegradation

Many factors affect the rate and extent of biodegradation of PCBs in the environment, including the percent chlorine composition of the isomers and Aroclor blends; the concentration of the compound; temperature; moisture; indigenous microbial population; aerobic or anaerobic conditions; presence of other carbon sources; and other factors, many of which are not well understood. PCBs are fairly resistant to biodegradation, however, isomers with fewer than four chlorine atoms per ring do degrade in a variety of environmental media (Callahan et al., 1979 , Smith et al. 19--).

Biodegradation of the lower-chlorinated isomers occurred in activated sludge (e.g., metabolism by bacteria),with 81 percent degradation of Aroclor 1221 in 48 hours, (Griffin and Chian, 1980) and with mixed cultures of soil microbes. Generally, bacteria are not able to metabolize PCB compounds with more than three chlorine atoms per ring. Higher organisms are more able to metabolize the higher-chlorinated PCB compounds. (Nisbet, 1976). Aquatic invertebrates can slowly metabolize tetrachlorobiphenyls (four chlorines per ring) and pentachlorobiphenyls (five chlorines per ring). Birds and mammals metabolize these compounds more readily, but have difficulty with hexachlorobiphenyls (six chlorines per ring) and

more highly-chlorinated PCBs. Jensen and Sundstrom (1974) showed that PCB isomers with 3 or 4 chlorine atoms (as are found in Aroclors 1254 and 1260) are more easily metabolized by humans than those with only one or two chlorine atoms (as predominate in Aroclors 1016 and 1242). Although most PCB biodegradation processes result in the formation of hydroxy-chlorobiphenyls, there is evidence for the formation of chlorinated dibenzofurans in chickens and rats (Nisbet, 1976). Thus, the biodegradation of PCBs does not necessarily represent detoxification of the compounds.

Bioconcentration

Biotic flux, i.e. the transport out of environmental compartments via uptake by organisms, can be a substantial mass transfer pathway for PCBs (Nisbit and Sarofim, 1972). As hydrophobic, lipophilic compounds, PCBs are readily taken up by biota. This bioconcentration is a function of the ambient concentration of PCBs, the organisms under consideration, their age, size, and other factors. It has been recognized, for instance, that the higher chlorinated PCB blends are bioconcentrated to a greater extent than are the lower chlorinated blends (Callahan et al., 1979). The preferential storage of higher-chlorinated PCBs can result in a higher average chlorine composition in the PCBs stored than were present in the original mixture.

In the estuarine environment, PCBs can enter the food chain in either particulate or soluble form (Mitchell, 1974).

They adsorb readily to organic detritus, clay, and phytoplankton (Harding and Phillips, 1978), and enter higher trophic levels through the ingestion of food, sediment and water, with subsequent absorption in the gut; absorption through respiratory surfaces; or adsorption to the body wall or exoskeleton (Swartz and Lee, 1980).

Both sediments and ambient water have been shown to contribute to the bioaccumulation of PCBs. Kiel et al. (1971) reported Aroclor 1242 concentrations in the marine diatom Cylindrica closterium 1100 times that of the ambient water. Similarly, Fowler et al. (1978) reported PCB bioconcentration factors in Nereis diversicolor, an annelid worm, of 800 in water and 3.5 in sediment. A similar range of bioconcentration factors is reported in Tables 2 through 15. The laboratory determination of the bioaccumulation potential of PCBs, which was used in the establishment of EPA criteria, was shown to be around 274,000 times the PCB level in the test water (Nisbet, 1976). Based on the relative concentrations in the water and sediments, Fowler et al. determined that 85 percent of the PCB body burden in N. diversicolor could be accounted for by direct uptake from the sediment, due to the relative concentration of PCBs there. Indications in that study were that the particulate fraction of the sediments had higher bioavailability than the interstitial water.

PCBs are strongly lipophilic (lipid loving), and thus one of the most significant factors affecting their accumulation and

partitioning in biota is the lipid content (fatty substances) of individual organisms. For both carp and channel catfish, Hunter et al. (1980) reported a positive correlation between the amount of lipid in fish fillets and the concentration of PCBs. Thomann et al. (1980) reported that PCB concentrations in striped bass were not significantly correlated with lipid content, however, such a correlation was found in trout, salmon and carp data cited by Thomann and St. John (1979). Graham (1976) found that the mean PCB level in fish oil was 32 times that of fish meal from which most of the oil had been extracted.

Due to variations in the lipid content of different tissues, and other metabolic differences, the bioaccumulation of PCBs can also vary within an individual organism. The data of McLeese et al. (1980) revealed that the hepatopancreas (tomalley) of lobsters had significantly higher PCB concentrations than either the tail or claw, with the tail having the lowest concentrations. Similar studies of lobsters dosed with PCBs revealed concentrations of Aroclors 1242 and 1254 in the hepatopancreas to be 15 times higher than those in the muscle, and concentrations in the eggmass 1.8 times higher than that of the hepatopancreas (Bend et al., 1976). Hansen et al. (1971) reported that concentrations of Aroclor 1254 in spot, an estuarine demersal fish, were highest in the liver, followed by the gills, the whole fish, the heart, the brain, and the muscle. Additionally, Klauda et al. (1981) noted PCB

concentrations in the liver of tomcod 30 times higher than in the gonad, and 184 times higher than in the remainder of the organism.

Rapid decreases in PCB concentration during spawning were observed in quahogs (Deubert et al., 1981) and oysters (Parrish, 1974; Wilson and Forester, 1978), indicating that PCBs may be stored in the gonadal tissue of these shellfish, and eliminated in the gametes. Thus, the sex and reproductive state of an organism may influence the bioaccumulation rate, due to metabolic changes in lipid deposition (e.g. with many species, females tend to be larger and have a higher lipid content than males).

Variation in rates of PCB bioaccumulation among individual organisms of the same species may also be attributed to the sex, size, and age of the organisms. For both plankton and fish, increasing organism size appears to relate to increasing concentration. Older fish may retain higher body burdens of PCB, due to reduced excretion rates (Thomann and St. John, 1979). Fish experiencing highly variable temperatures and faster growth rates have been found to accumulate PCBs at a faster initial rate, and to achieve significantly higher concentrations at high body weights (Spigarelli et al., 1983). The effect of temperature fluctuations is attributed to associated increases in feeding, growth, and lipid deposition, which thereby enhance the uptake of lipophilic compounds.

The reproductive state, size, and age of an organism may also be related to changes in habitat, which in turn can affect

PCB uptake. The American eel for example, is a catadromous fish which spawns in the Sargasso Sea, but spends most of its life in coastal estuaries and freshwater streams. The females move further inland than the males. Generally, eels seek a muddy bottom habitat and lie buried in the mud during the daytime, and most of the winter (Bigelow and Schroeder, 1953). Consequently, eels are most likely to accumulate substances like PCBs during the portion of their life cycle which brings them closest to sources of contamination. Their extensive contact with bottom sediments and absence of large surface scales, as well as their high lipid content, make them particularly susceptible to PCB accumulation. Fisheries data collected by Graham (1976) supports this conclusion. In a survey of PCB levels in commercial marine fish harvested in Canada, Graham found average concentrations of 0.56 ppm PCB in eels caught in marine waters and 7.27 ppm in eels caught in the St. Lawrence River. Eels from the St. Lawrence were higher in PCB concentration than any other commercial species. Of the freshwater eels, the smallest individuals averaged 2.95 ppm PCB, and the largest averaged 12.37 ppm. This distinction may have been related to body size alone, or to sexual differences, since females are generally larger than males.

Bioaccumulation of PCBs can reach an equilibrium, with the steady state concentration varying according to the species, the tissue, and the PCB source and concentration. Sanders and Chandler (1972) observed a time of 7 days to a steady state

concentration in mosquito larvae, and more than 21 days in glass shrimp. Striped bass larvae reached steady state in 48 hours, with 80 percent of the final concentration accumulated during the first 12 hours (Califano et al., 1980). This relatively short time to equilibrium may have been due to PCBs becoming limited in the system, as the larvae had already accumulated 60 percent of the available PCB. Spot took 42 days to reach an equilibrium concentration (Hansen et al., 1974). In all of the above studies, the source of the PCBs was ambient water containing between 1 and 1.5 ppb Aroclor 1254. Time to equilibrium is quicker in ingestion of water than by other sources. When the time to equilibrium is longer, an organisms physiological state may change such that a true equilibrium is never reached (Nisbet, 1976).

As with the actual bioconcentration factors, different tissues within an organism exhibit different equilibrium dynamics. In a study of lobsters fed mussels containing two of the PCB isomers, tetrachlorobiphenyl and hexachlorobiphenyl, concentrations of both isomers in the lobster hepatopancreas reached a steady state in 28 days, but the tail and claw tissue levels were still increasing after 42 days (McLeese et al., 1980).

Similar trends in the rate of depuration after removal of the PCB source seems to indicate a reversible metabolic process. In the lobster study described above, 80 percent of the tetrachlorobiphenyl was purged from the tail and claw tissue in 6

weeks, at which time concentrations in the hepatopancreas had decreased by only 60 percent. Results were similar for hexachlorobiphenyl, with a 90 percent decrease in the claw and 40 percent decrease in both the tail and the hepatopancreas (McLeese et al., 1980). Bend et al. (1976) also reported that the muscle tissue of lobsters depurated much more quickly than either the hepatopancreas or egg masses.

Depuration studies of oysters showed a decrease in PCB concentration to a steady state level, which was possibly sustained by the resuspension of contaminated sediments (Wilson and Forester, 1978). Califano et al. (1980), demonstrated that larval striped bass placed in clean seawater for 48 hours eliminated 18 percent of the total PCBs they had accumulated. The rate of elimination was reportedly fastest during the second 24 hours.

Trophic Transfer

The bioconcentration of PCBs in a sector of the food web is affected not only by the ambient environment and organismal morphology/physiology, but also by the food sources of the organisms. Accumulated PCBs are readily transferred from prey to predator. In a study of PCB bioconcentration in brown trout, Spigarelli et al. (1983) determined that less than 5 percent of the total accumulated PCBs were derived from ambient water, with the remainder coming from the food source, in this case, alewife.

As PCBs are transferred to successive trophic levels, their concentrations can be magnified. Thomann et al. (1980)

reported a 10 fold increase in estuarine food chain PCB concentration from phytoplankton to striped bass in the Hudson River Estuary. Trophic transfer of PCBs does not, however, always result in the magnification of PCB concentration, due to variations in diet.

The diet of an organism is obviously not independent of its habitat. In an estuary, for example, bottom dwelling primary consumers feed on microorganisms, benthic invertebrates, organic detritus and plant material, all of which can accumulate PCBs from contaminated sediments. In an Oklahoma stream where the sediments were heavily laden with PCBs, Hunter et al. (1980) determined that the concentration of PCBs in detritovores (carp) was significantly greater than in either omnivores (catfish) or carnivores (bass and crappie). However, other factors may have a stronger influence on PCB accumulation than does the diet. Graham (1976) found that, of the commercial marine fish caught in Canada, demersal (bottom dwelling) species generally had a lower PCB body burden than did pelagic (open water) species. One explanation for this might be a higher average lipid content and body size in the pelagic species. Bluefin tuna, a high trophic level consumer and probably the largest of the commercial species, had average PCB concentrations of 2.6 ppm, more than 6 times that of other pelagic fish (0.4 ppm), and 25 times the average concentration of the demersal fish.

Migration

The migration of organisms, e.g. the seasonal movement of birds or the passage of eel larvae from the ocean to inland streams, necessarily results in the migration of any toxic substances which they have bioaccumulated. Thus, the fate of PCBs in the environment can be far more complex and far-reaching than can be described by physical transport processes alone. In the Hudson River Estuary, for example, a wide range in PCB concentrations in striped bass is attributable to the seasonal migration characteristics of these anadromous fish (Thomann and St. John, 1979). Concentrations in eels will also vary significantly with their migratory patterns. Fall sampling of eels from an estuary, for example, might reveal significantly higher PCB concentrations than would sampling in the spring, since the fall catch would include large females returning to the sea from inland waters, and the spring catch would consist primarily of resident males and young females in the process of moving landward. Consequently, migration can have a significant effect on both the flux of PCBs in the environment, and the variation in concentration of PCBs in the biological community of any given locale.

Toxicological Effects of PCBs

The toxicity of PCBs is highly variable, both in magnitude and in effects (Tables 2 through 15). In some situations, PCBs can be lethal and in others, sublethal, but causing some physical disorder. For example, PCBs in various concentrations have been shown to be lethal to phytoplankton (Moore and Harriss, 1972); diatoms (Biggs et al., 1980; Fisher, 1975); shrimp (Nimmo et al., 1974; Duke et al., 1970); shellfish (Duke, 1974) and finfish (Hansen et al., 1971, 1976; Nebeker et al., 1974; Defoe et al., 1977; Johansson et al., 1970; Jensen, 1970; Duke, 1974; Schimmel et al, 1974).

At sublethal levels, PCBs have been reported to cause lesions in the gills and liver of fish (Walker, 1976; Duke, 1974); increased thyroid activity in coho salmon (Walker, 1976); beak abnormalities (Wassermann et al., 1979) and general limb weakness (Bagen and Bourne, 1972) in birds; hair loss, acne, and degenerative changes in the liver and central nervous system of monkeys (Wassermann et al, 1979); and skin lesions (Schwartz and Peck, 1943) and increased liver enzyme activity (Risebrough, 1969) in humans.

PCBs can also result in behavioral aberrations and effects which alter community structure. These compounds have been implicated as a cause of reproductive failure and deficiencies in Daphnia (Nebeker and Puglis;, 1974); fathead minnows and flagfish (Nebeker et al, 1974); Atlantic salmon (Hogan and Brauhn, 1972;

Johansson et al, 1970; Jenson, 1970); and birds, mink and sea lions (Wassermann et al., 1979). Relatively low levels of PCB have been reported to inhibit the growth, photosynthetic activity and productivity of phytoplankton (Biggs et al., 1980) and diatoms (Moore and Harriss, 1972; O'Connors et al., 1978; Mosser et al., 1977; Fisher, 1975), and the growth of lake trout (Walker, 1976). Particularly in complex ecosystems, e.g. estuaries, any such impacts on the lowest tropic levels can profoundly affect the entire ecosystem.

PCBs exhibit selective toxicity, whereby different biological species vary in their sensitivity to the chemical compounds. For example, 100 ppb of Aroclor 1254, with 48 hours exposure time was reported to have no effect on juvenile pinfish, but was 100 percent lethal to pink shrimp (Duke, 1974). Sheepshead minnow fry are considered to be the most sensitive estuarine organism, with 50 percent mortality at 0.1 ppb Aroclor 1254 and 100 percent mortality at 3 ppm, a level at which adults were unaffected after 4 weeks (Duke, 1974; Schimmel et al., 1974). This selective toxicity can significantly affect the community structure in an ecosystem. PCB concentrations of 5 to 10 ppb, for example, have been found to inhibit the growth, photosynthesis and productivity of Chlorella, altering its species composition and size (Biggs et al., 1980), while a concentration of 1000 ppb did not inhibit the growth of another green flagellate, Dunnaliella tertiolecta. Concentrations up to 10 ppb PCB even increased the competitive success of this organism (Mosser et al; 1977).

Of the many PCB compounds, the formulations with 3 to 5 chlorine atoms per biphenyl, as predominate in Aroclors 1242 and 1248, appear to be the most toxic to fish (Walker, 1976). This suggestion is substantiated by Nimmo et al. (1974), who reported that the LC_{50} (concentration resulting in 50 percent mortality) with adult scud was 2400 ppb Aroclor 1254 and only 52 ppb Aroclor 1248. Nebeker et al. (1974), however, found that the MATC (maximum acceptable toxicant concentration, e.g. the threshold concentration at which the substance begins to have toxic effects on a given organism) for fathead minnow was lower with Aroclor 1254 than with Aroclor 1242. Duke (1974) found that with both oysters and pink shrimp, Aroclor 1254 was more toxic than Aroclor 1016, yet the latter is one of the lesser chlorinated blends, with an average of 41 percent chlorine.

One factor which may influence the relative toxicity of different PCB compounds is the duration of time for which organisms are exposed to them. For example, juvenile pinfish exposed to 100 ppb Aroclor 1254 for 2 days suffered no mortality, yet there was more than 50 percent mortality after 12 days (Hansen et al., 1971). Stalling and Mayer (1972) reported that the oral toxicity of Aroclors 1242 and 1248, as well as 1254, to cutthroat trout increased greatly over long exposure periods, and also with increased temperature. Similar results have occurred with channel catfish and rainbow trout (Hansen et al., 1971), and with pink shrimp (Duke, 1974). In all likelihood, this chronic toxicity is the result of PCB bioconcentration to levels well

above that of the ambient environment, and beyond the threshold of toxicity.

From a review of selected literature, it is obvious that the chemical, physical and biological characteristics of PCBs affect their transport, fate and effects in the environment. This general review serves as the foundation for interpretation and comparison of the Acushnet Estuary PCB data base; for identification of critical data deficiencies; and development of resource management decisions related to effective remedial action.

SECTION 2

SECTION 2

ASSESSMENT OF THE ACUSHNET ESTUARY

PCB DATA BASE

Data Management

General

The Acushnet Estuary PCB data base presently contains more than 5,000 individual data entries, representing approximately 3,700 PCB analyses and 1,400 analyses of other parameters, primarily heavy metals. It reflects the efforts of 21 data collecting agencies and 23 analytical labs over the past ten years. Almost all of the data contained in the file are from the Acushnet Estuary, surrounding land, and adjacent Buzzards Bay. Each data entry includes the following information, where relevant and available:

- Sample identification (sample, station and lab numbers).
- The agency which performed the study.
- Sample type, in several levels of detail.
- Location of sampling (x, y coordinates) and date and time of sample collection.
- The lab which performed the analysis, the date of analysis, and the analytical methods used.
- The parameter analyzed, measured concentration, units of measurement, detection limit, and solids content of the sample.
- Any additional information and comments.

Data Evaluation

In order to ensure the quality of the data base, all of the data were screened using criteria developed to evaluate the reliability of each measurement. Based on this evaluation, the data were divided into three categories: "reliable" data, or those for which the sample collection and analytical methods were documented and possess a reliability worthy of the fullest confidence; "incomplete" data, for which the documentation necessary to ascertain the reliability was unobtainable; and "unusable" data, which possessed collection and/or analytical deficiencies which precluded their use.

Figure 2 illustrates the procedure used in evaluating the data. In cases where quality control documentation was not available to substantiate the analyses, the data was designated "reliable" only if the laboratory performing the analysis maintained State certification for the analysis of pesticides, herbicides and volatile organics (under Section 304(s) of the Federal Water Pollution Control Act), thus proven procedures (40 CFR Part 136) were used. This certification, coordinated through the Quality Assurance Branch of the U.S. Environmental Protection Agency's regional offices, includes the comparative analysis of split samples by participating laboratories.

On the basis of this data evaluation, 91 percent of the data base was deemed reliable, 5 percent incomplete, and 4 percent unusable. All subsequent references in this report to the PCB data, unless otherwise indicated, are based only on the "reliable" data base.

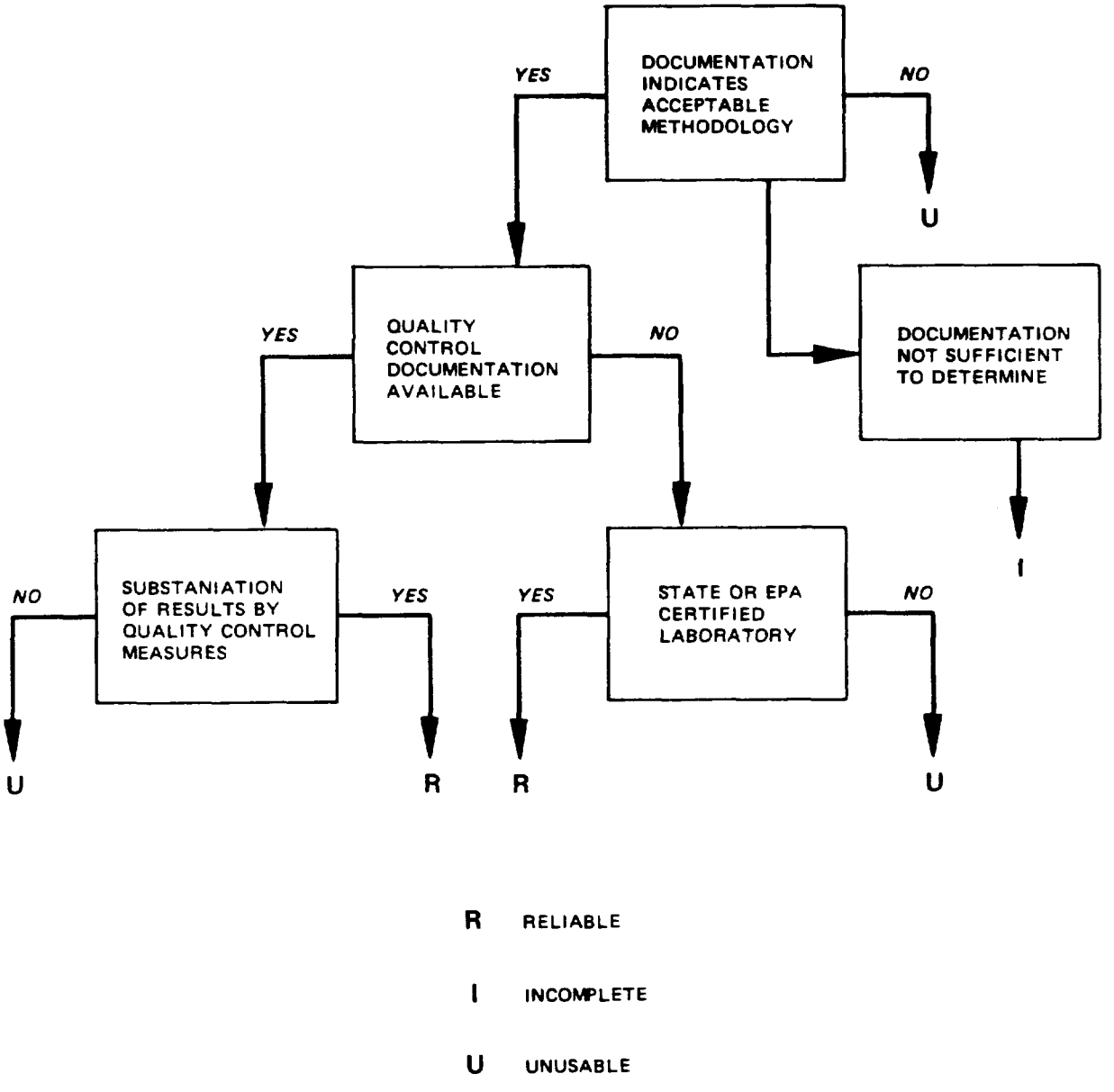

FIGURE 2. USE OF DATA EVALUATION CRITERIA

Objectives

Once the reliability of the data base was established, its actual utility was examined relative to its contributing essential information regarding:

- The location and severity of contamination in the Acushnet Estuary area.
- The specific contaminants present.
- The critical pathways (physical, chemical and biological) and fate processes acting in the transport and partitioning of contaminants in the estuary.
- The implications of contamination, including public health hazards, the health of the ecosystem, and economic impacts.
- The effectiveness and impacts of potential cleanup alternatives.

The following discussion summarizes and assesses the existing reliable data relating to these issues in the Acushnet Estuary; describes the approaches used in making the assessment; and identifies apparent data gaps as well as critical areas requiring remedial action.

Data Base Assessment

Location and Severity of Contamination

Table 16 summarizes the major sample types included in the data base. (A more detailed breakdown of sample types is

TABLE 16. SUMMARY OF "RELIABLE" DATA BASE

Sample Type	Number of Data Entries
Air	43
Sediment	2729
Waste	199
Water	223
Lobster	346
Blue Mussel	90
Quahog	540
Winter Flounder	56
Misc. Shellfish (6 Species)	23
Misc. Finfish (19 Species)	140
Misc. Sample Types (6)	195

contained in Appendix A). More than 50 percent of the nearly 4,600 data entries represent analyses of estuarine sediments, and 4 percent are water column analyses from the estuary. An additional 26 percent of the data are analyses of aquatic biota. Thus, more than 75 percent of the existing data base comprises samples from the Acushnet Estuary itself, as opposed to land-based locations such as the disposal sites, industrial plants, and municipal facilities. This fact in itself may indicate a significant data gap, although the estuary is where the most pervasive contamination has occurred.

The PCB data base file contains approximately 250 data records from analyses of various wastes. Most of these data represent wastewater, sediment, sludge, grit and ash samples from the New Bedford sewer system and water and wastewater treatment facilities, although there are also some data from the industrial processes at Aerovox Incorporated and Cornell-Dubilier Electronics. Of the sewer system data, the only measurable PCB concentrations occurred at and below the Cornell-Dublier plant. As recently as 1981, concentrations of 63 mg/l Aroclor 1016 were measured in the sewer system by the Massachusetts DEQE. Within the treatment facilities, PCBs are concentrated in the sludge to levels as high as 190,000 ppm (dry wt) Aroclors 1242/1254.

Studies involving the monitoring of PCB levels in the ambient air of the Acushnet Estuary area revealed concentrations (in 139 records) ranging from nondetectable to 800 ng/m^3 Aroclors 1016/1242. The highest concentrations were measured by EPA in

1977 and 1978 at the two capacitor manufacturing plants in New Bedford, Aerovox Incorporated and Cornell-Dubilier Electronics. More recent sampling (in 1982) at these locations revealed significantly lower concentrations, within a range of less than 1 to 100 ng/m^3 Aroclors 1016/1242 in the vicinity of Aerovox, and less than 10 ng/m^3 near Cornell-Dubilier. This recent study (by EPA) showed the highest ambient air concentrations (140 ng/m^3 Aroclors 1016/1242) to occur at the former dump site on Sullivan's Ledge. Most of the New Bedford area air monitoring has been conducted in areas of known or suspected PCB contamination. There are relatively few data records representing "background" PCB levels in the air around New Bedford and Fairhaven.

Tables 17 and 18 summarize PCB concentrations in estuarine sediment and biota samples taken from the Acushnet Estuary itself; in the Inner New Bedford Harbor (above the hurricane barrier), and in the Outer Harbor (between the hurricane barrier and Clark's Point). Particularly in the Inner Harbor, the Acushnet River Estuary is one of the most severely PCB contaminated estuaries in the world.

For example, sediments in Raritan Bay, at the mouth of the heavily PCB contaminated Hudson River between New York and New Jersey, contained PCBs at concentrations of 0.003 to 2.0 ppm (dry weight) (Stainken and Rollwagen, 1979). Bopp et al. (1981) reported PCB levels in the lower Hudson River of 0.7 to 5.8 ppm (dry weight). Sediment PCB concentrations further up the

TABLE 17. PCB CONCENTRATIONS IN INNER HARBOR, ACUSHNET ESTUARY

	No. of Records	Minimum	Maximum	Median	Mean
Sediments (ppm dry wt.)					
Aroclors 1221; 1232	58	ND	ND	ND	ND
Aroclor 1016	110	ND	0.3	ND	0.1
Aroclor 1242	75	ND	730	ND	1.0
Aroclor 1248	85	ND	5100	29	333
Aroclor 1254	323	ND	66500	13	1221
Aroclor 1260	58	ND	ND	ND	ND
Biota (ppm wet wt.)					
Quahog					
Aroclor 1221; 1232; 1242	--	--	--	--	--
Aroclor 1016	--	--	--	--	--
Aroclor 1248	--	--	--	--	--
Aroclor 1254	3	0.1	1.6	0.5	0.8
Aroclor 1260	--	--	--	--	--
Eel					
Aroclor 1254	14	11	730	240	264
Winter Flounder					
Aroclor 1254	5	6	22	11	11
Lobster					
Aroclor 1242	--	--	--	--	--
Aroclor 1248	--	--	--	--	--
Aroclor 1254	--	--	--	--	--
Aroclor 1260	--	--	--	--	--

TABLE 18. PCB CONCENTRATIONS IN OUTER HARBOR, ACUSHNET ESTUARY

	No. of Records	Minimum	Maximum	Median	Mean
Sediments (ppm dry wt.)					
Aroclors 1221; 1232	44	ND	ND	ND	ND
Aroclor 1016	63	ND	25	ND	0.4
Aroclor 1242	64	ND	34	ND	2.0
Aroclor 1248	68	ND	98	1.0	6.0
Aroclor 1254	92	ND	102	6.1	13
Aroclor 1260	77	ND	50	ND	0.7
Biota (ppm wet wt.)					
Quahog					
Aroclors 1221; 1232; 1242	14	ND	ND	ND	ND
Aroclor 1016	14	ND	ND	ND	ND
Aroclor 1248	15	ND	6.0	0.3	0.9
Aroclor 1254	30	ND	3.5	0.4	0.7
Aroclor 1260	14	ND	ND	ND	ND
Eel					
Aroclor 1254	3	12	38	14	21
Winter Flounder					
Aroclor 1254	15	0.2	8.3	2.5	3.0
Lobster					
Aroclor 1242	4	ND	ND	ND	ND
Aroclor 1248	5	2.0	21	8.7	11
Aroclor 1254	55	0.6	84	5.4	13
Aroclor 1260	4	1.0	3.1	1.7	2.0

Hudson River, near PCB point sources, were often greater than 50 ppm, and seldom less than 25 ppm (Clesceri, 1980). In the Escambia River Estuary, Florida, sediment PCB concentrations of 500 ppm (dry weight) near the source outfalls have been reported (Duke et al., 1970). In the vicinity of several wastewater treatment plant outfalls in the nearshore waters of San Diego, California, bottom sediments had a median of 0.022 ppm (dry weight) of PCB (Young and Hensen, 1977).

These New York, New Jersey and Florida estuarine locations are referred to in the literature as being severely contaminated, yet none of them have measured PCB concentrations approaching the more than 10,000 ppm (dry weight) found in the upper portion of the Acushnet Estuary. The median concentration of PCBs in the New Bedford Inner Harbor, at 29 ppm (dry weight) Aroclor 1248, is a full order of magnitude higher than in most of the other estuarine locations studied. Only in the upstream reaches of the Hudson River,New York and in the Escambia River Estuary, Florida have such high concentrations been reported. Median concentrations in the Outer Harbor area of the Acushnet Estuary are comparable to concentrations in the Hudson River Estuary, although the latter does not have measured concentrations nearly as high as 100 ppm (dry weight).

There have been 138 water column analyses in the Acushnet Estuary, all of which represent samples taken inside the hurricane barrier. Although concentrations in the water column

were to a large extent nondetectable (<0.5 ug/l), levels as high as 6.1 mg/l Aroclors 1248/1254 were measured.

PCB concentrations in biological organisms inhabiting the Acushnet Estuary are also indicative of contamination. Particularly for the Inner Harbor, however, the data are limited and therefore somewhat inconclusive. Of the organisms sampled, eels had the highest concentrations, with a median of 240 ppm (wet weight) Aroclor 1254 in the Inner Harbor and 14 ppm Aroclor 1254 in the Outer Harbor. Concentrations in quahog and winter flounder were also higher in the Inner Harbor than outside of the hurricane barrier, at 0.5 and 11 ppm Aroclor 1254 respectively. Lobsters sampled from the Outer Harbor were significantly contaminated with PCB levels of 8.7 ppm Aroclor 1248, but there are no lobster data for the Inner Harbor, where concentrations could be expected to be higher. The levels of PCBs in the Acushnet Estuary biota are generally much higher than those found in Escambia Bay, Florida (Duke et al., 1970); Raritan Bay, New York (Stainken and Rollwagen, 1979); and Boston Harbor, Mass. (Metcalf & Eddy, 1979).

In general, the range in PCB concentrations in the Acushnet Estuary is exceptionally wide, with Aroclor 1254 analyses of Inner Harbor sediments ranging from nondetectable to 66,500 ppm (dry weight). This wide range in concentration may be due to nonhomogeneity in the occurrence of PCBs in bottom sediments, or to variability in the analyses. Variability in PCB concentration in the biota is somewhat less than in the

sediments. The influence of a few very high concentrations on a data set is evident in the mean concentrations listed in Tables 17 and 18. Particularly in the sediments, the mean values are well above the median concentrations measured. Statistical analyses of the sediment data within 1 km^2 grid sections of the estuary revealed standard deviations greater than or equal to the mean. This distribution makes it very difficult to actually quantify the volume of PCBs in the estuary, or to comprehend the severity of contamination in any one area.

A more suitable way to analyze this contaminant distribution is with a spatial representation, which relates a measured concentration to its location in the environment. Spatial representation is particularly appropriate for the estuarine data, as opposed to air data, because it varies spatially with changing climatic conditions, and data from the sewerage system, which is essentially linear, according to the system layout. Data from upland disposal sites, such as the landfill, Sullivan's Ledge, and the additional unidentified sites referred to in the RAMP (Weston Associates, 1983), would also best be analyzed in a spatial sense (on an x-y plane as well as over depth), however the location of sampling of these sites, for the limited data in the existing data base, does not contain the information and precision necessary for such an approach. Although contamination does occur at these upland sites, the actual distribution of PCBs within the landfill and Sullivans' Ledge remain essentially undefined and merits more detailed

sampling. The focus of the remainder of this discussion is on the location of contamination within the Acushnet Estuary as defined by PCB concentrations in the estuarine sediments.

Utilizing a purely statistical approach, a linear regression analysis was performed on the estuarine sediment data to determine whether there was any correlation between PCB concentration and location along the length, or y axis, of the estuary. Both Aroclor 1248 and Aroclor 1254 concentrations exhibited a statistically significant ($P < 0.01$) positive correlation with north/south position in the Acushnet River Estuary, north of the hurricane barrier. Sediment concentrations are highest at the top (north end) of the estuary, decreasing further south towards the mouth of the harbor. Concentrations of Aroclors 1016 and 1242 were not significantly correlated with north/south position. There was no significant correlation shown for concentrations of any of the Aroclors between the hurricane barrier and the Clark's Point/Wilbur Point transect, although there was (with Aroclors 1248 and 1254) for the entire length of the estuary, from Clark's Point to just north of Aerovox. This may be due either to the influence of the treatment plant outfalls at Clark's Point, the widening of the estuary south of the hurricane barrier (probably resulting in more east/west transport), or the relative sparseness of data in the southern portion of the estuary. In order to better illustrate these trends, and to permit the interpretation of large amounts of

data, a graphical approach to the data presentation was undertaken.

Preliminary delineation of the locations of sample collection and the distribution of contamination within the Acushnet Estuary utilized a vector based computer graphics system linked to the data base management system. Specific data sets, e.g., surface sediments, were selected, and their sample locations (listed as x,y coordinates in the USGS Transverse Mercator Grid System) were plotted on a digitized map of the estuary. Figure 3 is a sample of this mapping approach, showing sampling locations of shallow (4 to 8 cm deep) sediments in the estuary. Similar maps were generated for surface sediments (0 to 4 cm) and deep sediments (> 8 cm).

A second set of preliminary maps, depicting the PCB concentrations (within range intervals) associated with each sampling site, was developed for inclusion in the RAMP document (Weston Associates, 1983). Figure 4 is an example from this map set. It should be noted that both of these sets of preliminary maps were developed prior to completion of the data evaluation. They represent all of the data collected since 1977, not the entire data base. The basic mapping approach used here integrated the information pertaining to the location of PCB sampling with that relating the PCB concentrations measured. As Figure 4 illustrates, however, the large amount of data collected within relatively small areas of the estuary make the map somewhat "busy", and difficult to interpret. In order to provide

ESTUARINE SEDIMENT DATA
SOURCE: EPA REGION I ACUSHNET ESTUARY
PCB DATA MANAGEMENT SYSTEM
30 NOVEMBER, 1982

FIG. 3 SAMPLING LOCATIONS - ESTUARINE SHALLOW SEDIMENT DATA

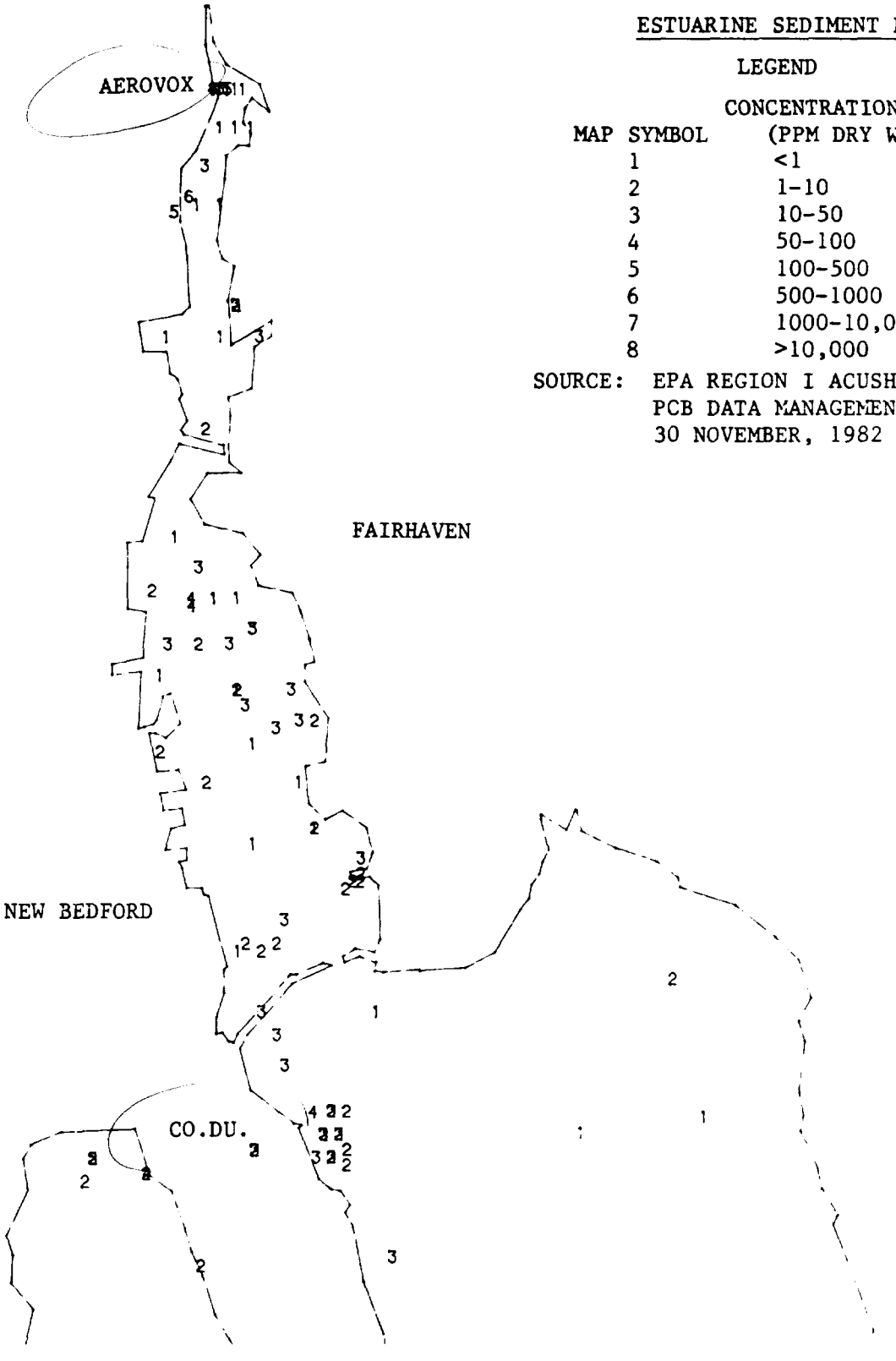

FIG. 4 ESTUARINE SEDIMENT DATA - AROCLOR 1254

a more easily readable, yet informative picture of the PCB distribution in the Acushnet Estuary, a similar approach was employed using color rastar graphics.

In this approach, sampling points were color coded according to the measured PCB concentration, in half-step log intervals. Ten colors were used to represent a range in concentration from less than 1 ppm (blue) to greater than 10,000 ppm (red) (Figure 5). These maps, the upper portions of which are presented in Figures 6 through 13, were prepared for each of four data sets: Aroclor 1248 in surface sediments; Aroclor 1254 in surface sediments; Aroclor in 1254 shallow sediments; and Aroclor 1254 in deep sediments, all derived from the entire reliable data base.

These color coded point maps are highly informative, regarding both the distribution of PCB contamination throughout the estuary, and the location of sampling efforts. The highest PCB concentrations occur in the upper end of the estuary, in the vicinity of the Aerovox Incorporated plant. This is also the location which has received the highest intensity of sampling. PCB concentrations measured in the area are primarily in the 1,000 to 5,000 ppm (dry weight) range, with some measurements above 10,000 ppm, and some below 1 ppm. Thus, PCB distribution in this highly contaminated area is somewhat "patchy". It may be that the mud flats along the shore of the river contain pockets of PCB-laden oils in some places, whereas other portions of the river have been swept relatively clean. Variations in measured

FIGURE 5. COLOR-CODED COMPUTER GRAPHICS - LEGEND

CONCENTRATION PPM DRY WEIGHT	
50–100	ABOVE 10,000
10–50	5,000–10,000
5–10	1,000–5,000
1–5	500–1,000
BELOW 1	100–500

One Kilometer

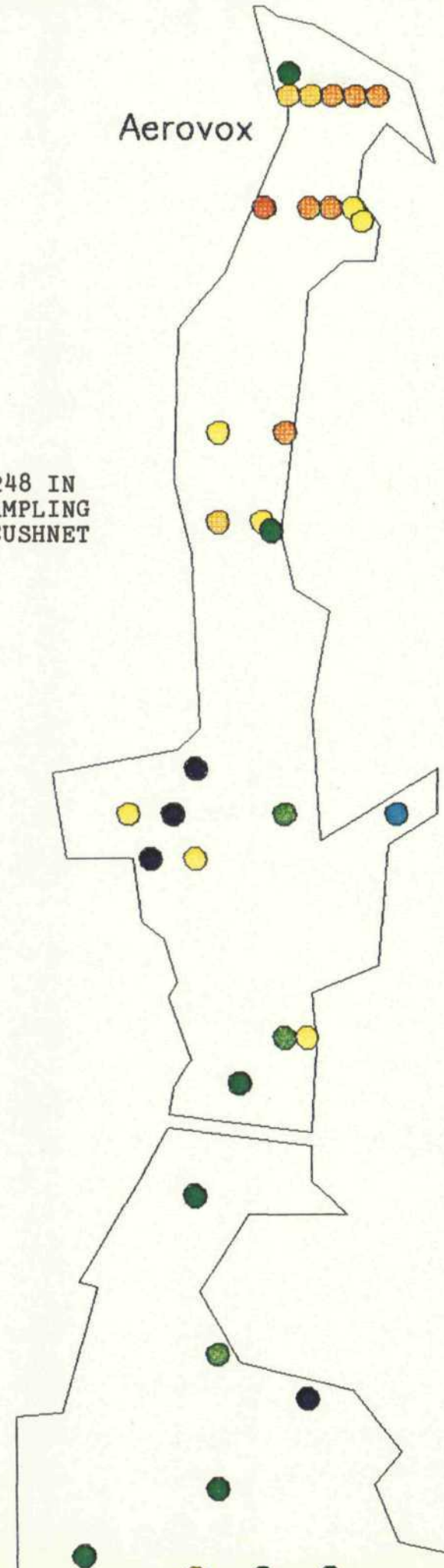

FIGURE 6. AROCLOR 1248 IN SURFACE SEDIMENTS, SAMPLING LOCATIONS IN UPPER ACUSHNET ESTUARY

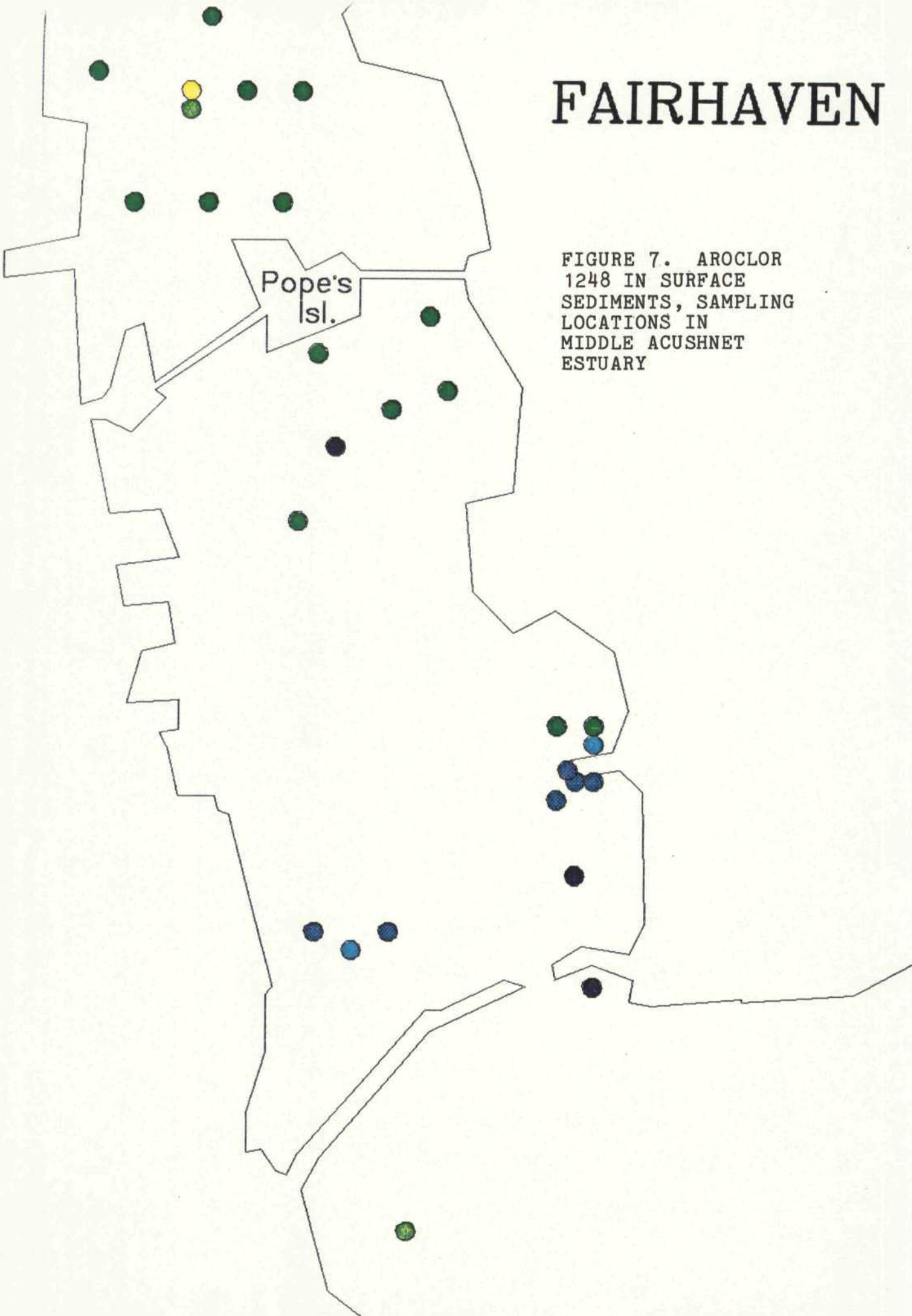

FIGURE 7. AROCLOR 1248 IN SURFACE SEDIMENTS, SAMPLING LOCATIONS IN MIDDLE ACUSHNET ESTUARY

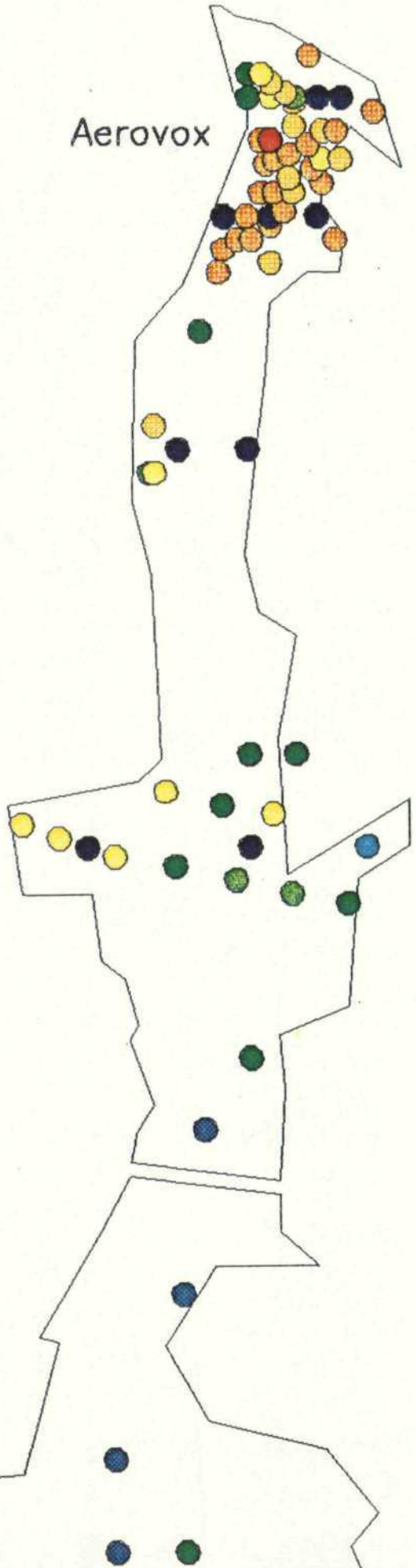

FIGURE 8. AROCLOR 1254 IN SURFACE SEDIMENTS, SAMPLING LOCATIONS IN UPPER ACUSHNET ESTUARY

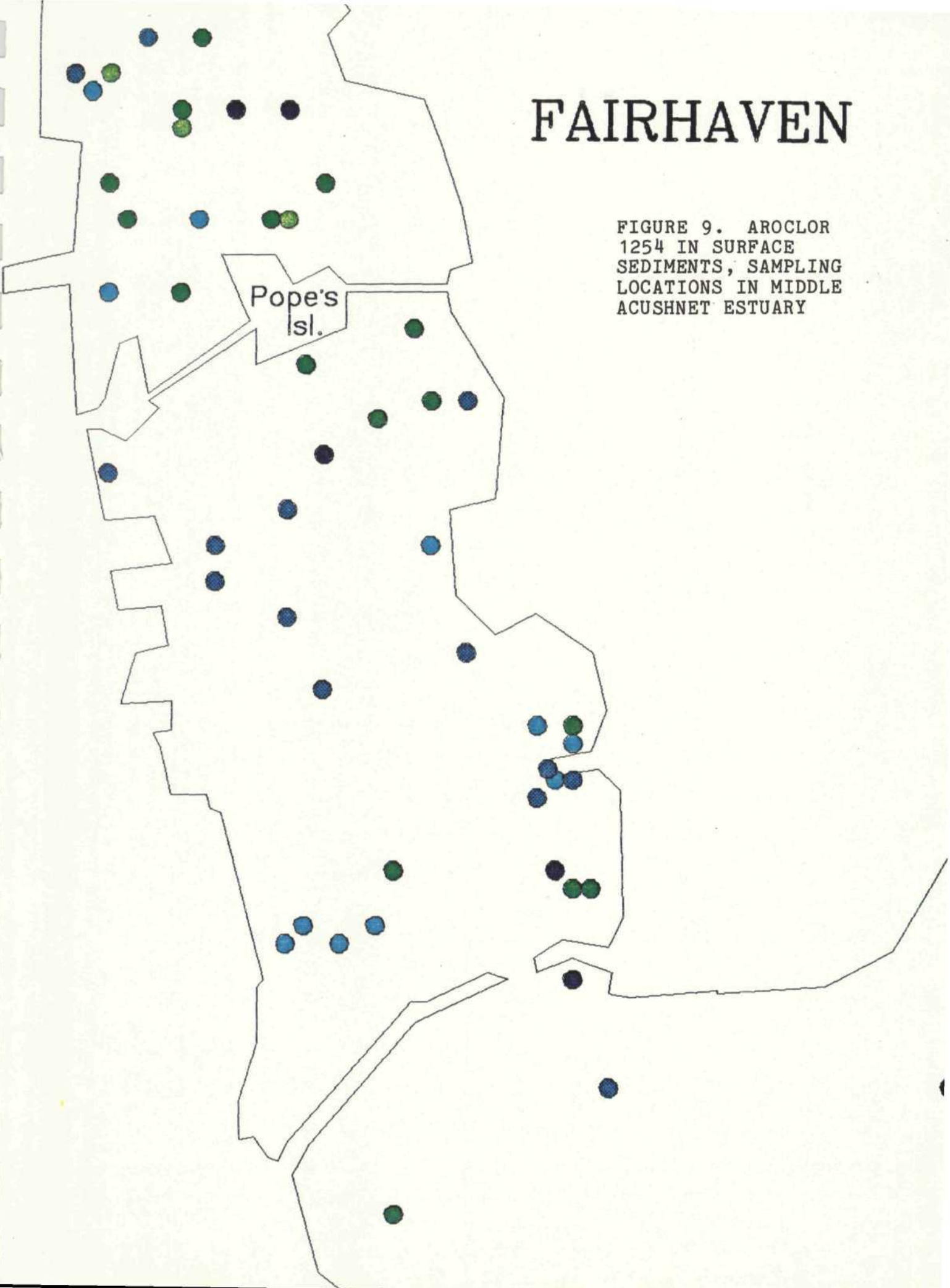

FIGURE 9. AROCLOR 1254 IN SURFACE SEDIMENTS, SAMPLING LOCATIONS IN MIDDLE ACUSHNET ESTUARY

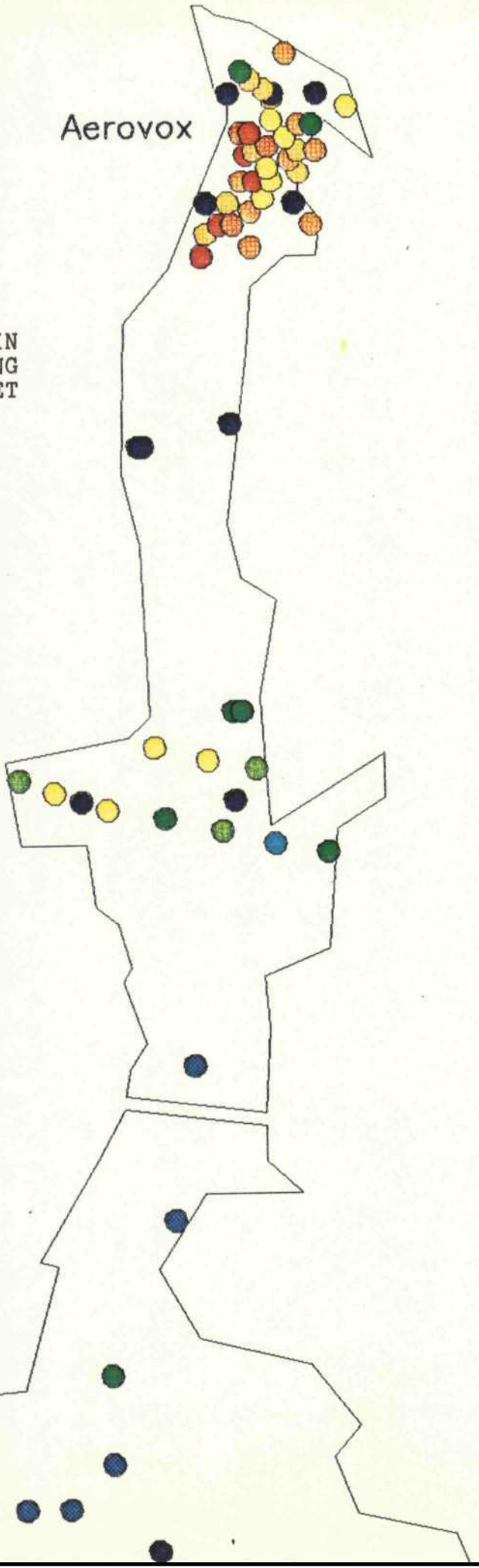

FIGURE 10. AROCLOR 1254 IN SHALLOW SEDIMENTS, SAMPLING LOCATIONS IN UPPER ACUSHNET ESTUARY

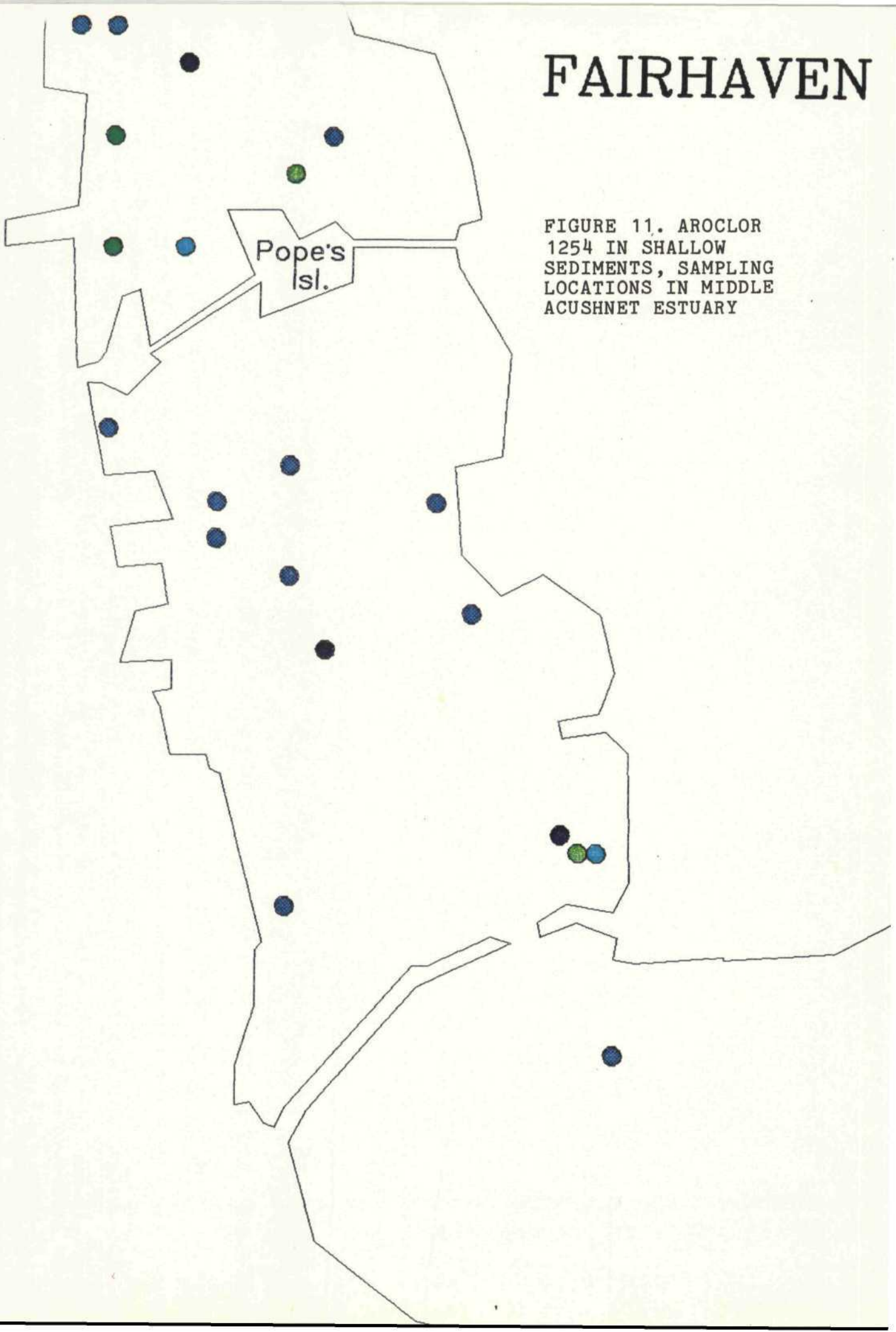

FIGURE 11. AROCLOR 1254 IN SHALLOW SEDIMENTS, SAMPLING LOCATIONS IN MIDDLE ACUSHNET ESTUARY

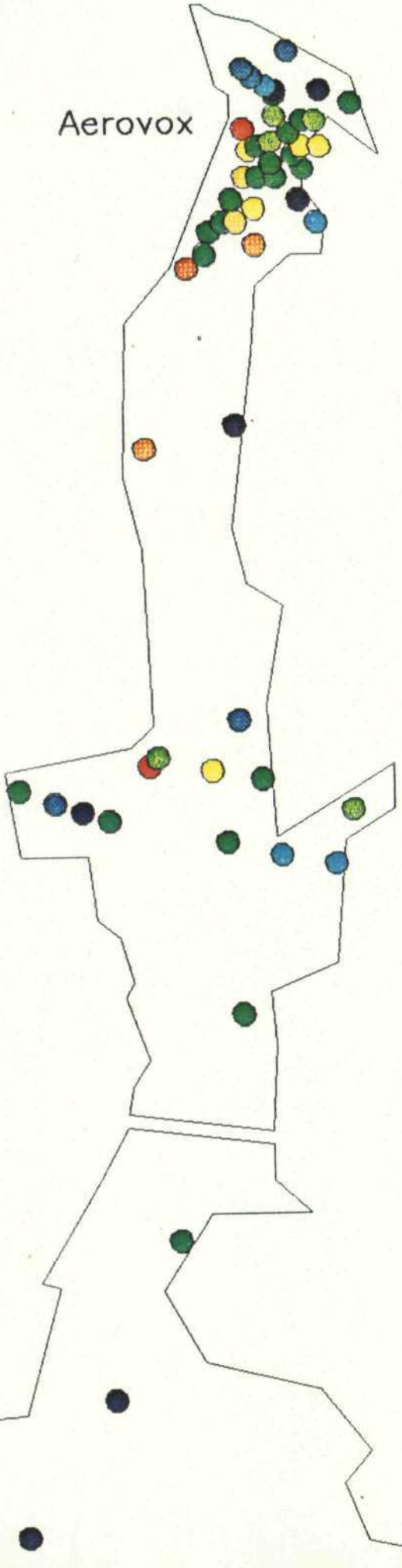

FIGURE 12. AROCLOR 1254 IN DEEP SEDIMENTS, SAMPLING LOCATIONS IN UPPER ACUSHNET ESTUARY

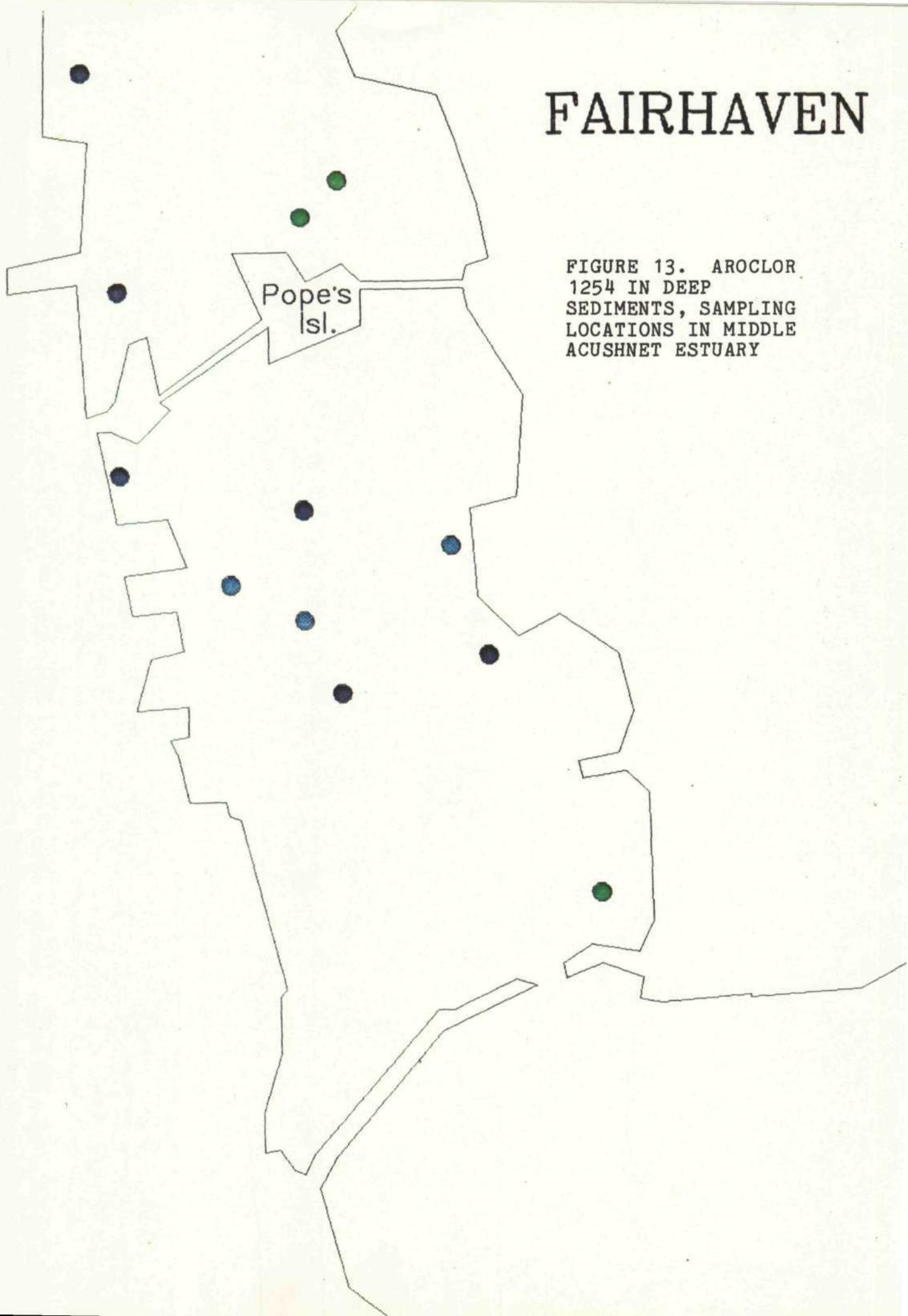

FIGURE 13. AROCLOR 1254 IN DEEP SEDIMENTS, SAMPLING LOCATIONS IN MIDDLE ACUSHNET ESTUARY

PCB concentrations may also be due to inconsistency in the analyses. More precise delineation of "hot spots" in the immediate vicinity of Aerovox Inc. may warrant further sampling for cost-effective remedial action.

Samples taken throughout the remainder of the Inner New Bedford Harbor (north of the hurricane barrier) are fairly evenly distributed, as are their associated PCB concentrations. Between the Coggleshall Bridge and the "hot spot" near the industrial complexes, concentrations are predominantly in the range of 10 to 500 ppm (dry weight). Along the narrow neck south of the industrial complex, there is a one kilometer stretch of river which has been sampled considerably less than the rest of the harbor, thus concentrations there remain relatively undefined. From the Coggleshall Bridge south to the hurricane barrier, PCB concentrations measured have almost all been less than 100 ppm (dry weight), but greater than 1 ppm.

In the Outer Harbor (south of the hurricane barrier) and in Clark's Cove, sediment sampling has been less extensive. The areas offshore of Cornell-Dubilier Electronics, the New Bedford sewage treatment plant at Clark's Point, and the combined sewer overflows in Clark's Cove have received the highest density of sampling, and all three locations have sediment PCB concentrations in the range of 5 to 50 ppm (dry weight). The remainder of the estuary, although sparsely sampled, has PCB concentrations mostly less than 5 ppm (dry weight), with only a few samples falling into higher ranges.

In an effort to apply the data regarding PCB concentrations in one location in the estuary to other unsampled locations, a geostatistical modelling concept known as "Kriging" was used to develop color contour maps of the estuary. This approach entailed the development of a "data semi-variogram" to evaluate the continuity of the data, then fitting a model to it which defined a radius for interpolation (Royle et al., 1981; Olea, 1974). This method enables the user to define barriers between points and to limit the model to "assumptions" which are statistically more valid. With respect to the Acushnet Estuary, this provided for definition of land barriers to PCB transport (e.g., the hurricane barrier), such that points on one side of a piece of land did not influence those on the other side in interpolation. In addition, portions of the estuary where data were too sparse and inconsistent for valid interpolation were identified as "undefined" and no contours drawn (these areas appear black on the maps).

Color contour maps using the Kriging approach were generated for the same four data sets as the color point maps: Aroclor 1248 in surface sediments, and Aroclor 1254 in surface, shallow and deep sediments (Figures 14 through 21, See legends on Figure 5). These data sets were the only ones with efficient sampling points to develop contours.

As with the color point maps, several trends in the data become immediately evident in viewing the contour maps. The most striking fact is that the most severe contamination is restricted

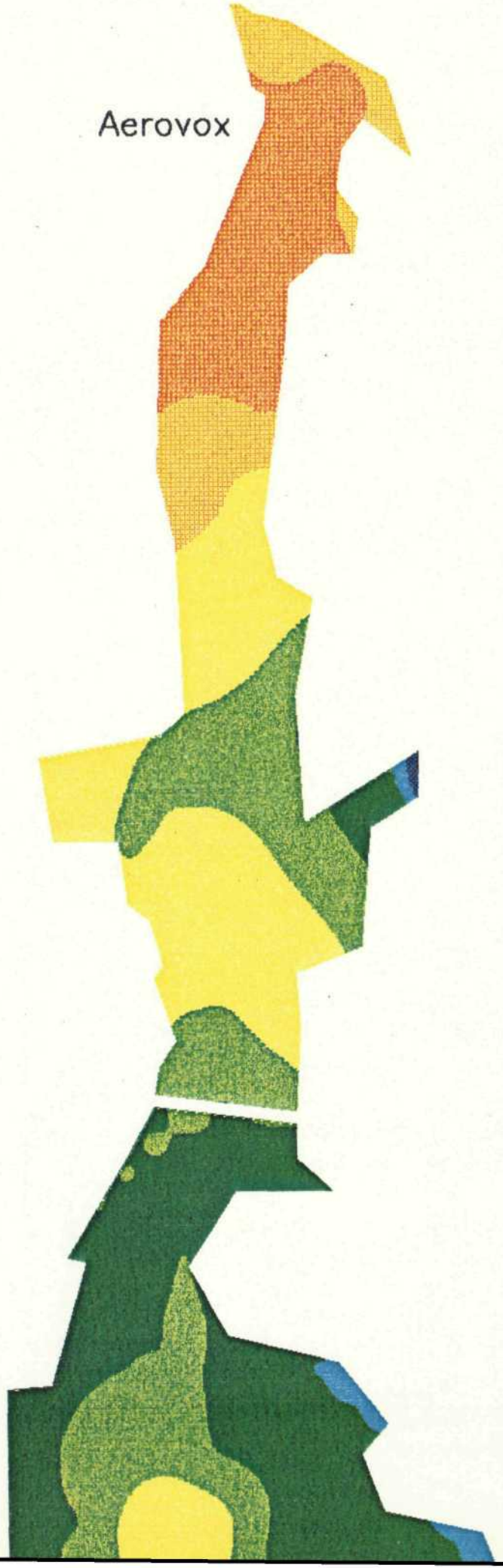

FIGURE 14. CONCENTRATION CONTOURS, AROCLOR 1248 IN SURFACE SEDIMENTS OF THE UPPER ACUSHNET ESTUARY

FIGURE 15. CONCENTRATION CONTOURS, AROCLOR 1248 IN SURFACE SEDIMENTS OF THE MIDDLE ACUSHNET ESTUARY

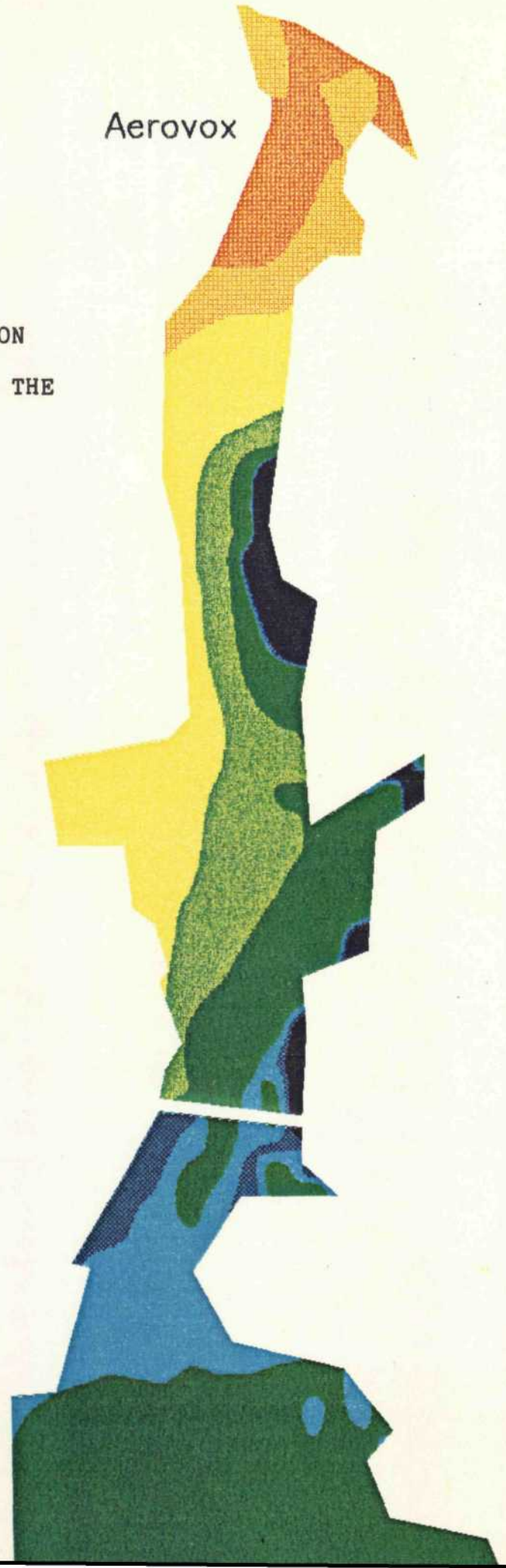

FIGURE 16. CONCENTRATION CONTOURS, AROCLOR 1254 IN SURFACE SEDIMENTS OF THE UPPER ACUSHNET ESTUARY

FIGURE 17. CONCENTRATION CONTOURS, AROCLOR 1254 IN SURFACE SEDIMENTS OF THE MIDDLE ACUSHNET ESTUARY

FIGURE 18. CONCENTRATION CONTOURS, AROCLOR 1254 IN SHALLOW SEDIMENTS OF THE UPPER ACUSHNET ESTUARY

FIGURE 19. CONCENTRATION CONTOURS, AROCLOR 1254 IN SHALLOW SEDIMENTS OF THE MIDDLE ACUSHNET ESTUARY

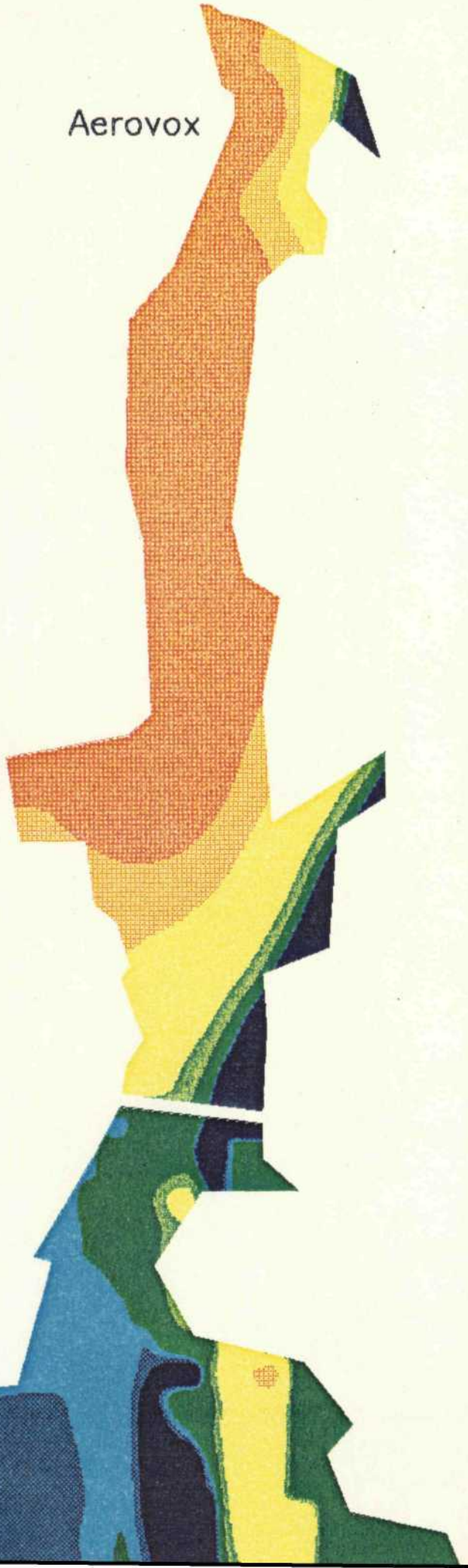

FIGURE 20. CONCENTRATION CONTOURS, AROCLOR 1254 IN DEEP SEDIMENTS OF THE UPPER ACUSHNET ESTUARY

FIGURE 21. CONCENTRATION CONTOURS, AROCLOR 1254 IN DEEP SEDIMENTS OF THE MIDDLE ACUSHNET ESTUARY

to the upper estuary, north of the Coggleshall Bridge. The high PCB concentrations in that area appear to emanate from the industrial complexes on the western shore of the river. In addition, some trapping of sediment PCBs behind land barriers at the bridges, and particularly at the hurricane barrier, is indicated.

Comparing the six maps of Aroclor 1254 concentrations (Figures 16 through 21), the highest concentrations in the upper estuary are in the shallow sediments, 4 to 8 cm deep. This is probably due to the fact that PCB discharge to the estuary was ended in 1977, and the most contaminated sediments have been covered by cleaner sediments since then. In the outer portions of the estuary, higher concentrations appear on the maps in the surface sediments than in deeper sediments. However, comparing the sampling point maps shows this to be because very few subsurface sediment samples were collected in the areas of highest surface sediment PCB concentration; around the treatment plant outfalls, the discharge pipe from Cornell-Dublier Electronics, and the CSO's in Clark's Cove. Thus, concentrations in the shallow and deeper sediments in these three areas are unknown. Given the historical deposition pattern indicated in the upper estuary, these subsurface sediments may be even more contaminated than the 10 to 50 ppm (dry weight) of PCBs in the surface sediments, and than the less than 5 ppm which they are shown to be on the contour maps. Consequently, additional sampling in

shallow and deep sediments in these areas is prescribed for development of effective remedial action.

To some extent, data gaps such as these are identified by the Kriging process, in the black "undefined" areas predominating in the outer estuary. However, as with any statistical model, interpretation of these contour maps must be approached with caution. The contours portray the average concentration measured within an area of approximately 2,500 square meters. Thus, they tend to smooth out some of the patchiness of the data. Given the high variability in PCB analysis and the relative imprecision of sample location, this results in a more conservative approach. However, a few extremely high measurements do tend to inflate the average concentration shown for a given area (e.g., at the northern end of the estuary). In addition, PCB levels are portrayed by the model as emanating from a source in all directions; a more detailed transport modeling is required to determine the actual direction(s) of travel. Consequently, these contour maps would best be used in conjunction with the point maps portraying the individual sample locations; the actual data listed in the data base file; and a reliable model of PCB transport in the estuary. Used in this manner, they provide an invaluable management tool in portraying the location of PCB contamination throughout the Acushnet Estuary.

Specific Contaminants Present

As is shown in Table 19, almost half of the PCB analyses conducted on samples from the Acushnet Estuary area have been

TABLE 19. PCB ANALYSES IN "RELIABLE" DATA BASE

PCB Blend(s)	No. Data Records
Aroclor 1016	338
Aroclor 1221	227
Aroclor 1232	227
Aroclor 1242	420
Aroclor 1248	295
Aroclor 1254	1246
Aroclor 1260	254
Aroclor 1262	48
Aroclors 1016/1242	27
Aroclors 1242/1254	31
Aroclors 1248/1254	43
"Total" PCBs	74

quantitated in terms of Aroclor 1254, implying that the distribution of PCB isomers in the samples taken are distributed on a gas chromotogram in a configuration most similar to the Aroclor 1254 standard. The data presented earlier in Tables 17 and 18, however, indicate that PCBs resembling the Aroclor 1248 configuration are also present in high concentrations in the estuary, perhaps even higher than as Aroclor 1254. Interestingly enough, neither of these commercial PCB mixtures was ever used in large quantities by the local industries. The two capacitor manufacturers in New Bedford, Cornell-Dubilier Electronics and Aerovox Incorporated, used primarily Aroclor 1242 prior to 1971, replacing it with Aroclor 1016 until 1977. Aroclors 1254 and 1252 were used in lesser quantities (Weaver, 1982). Even so, the measurements which have been made of the lower chlorinated Aroclors 1242 and 1016 reveal significantly lower concentrations in the estuarine sediments and biota than measurements of Aroclors 1248 and 1254. There are no data on Aroclor 1252 concentrations.

The fact that most of the PCB analyses have been quantitated in terms of Aroclor 1254 may be due to the fact that many labs use that standard as common practice, not necessarily because it is most applicable to the sample chromatogram. Farrington et al. (1981) expressed concern that this was the case and that, since they were finding mostly Aroclors 1016 and 1242 in the Acushnet Estuary sediments, the state of the art methods which measured only 1254 were low by a factor of two or more.

However, the high concentrations that have been measured using both the Aroclor 1248 and 1254 standards indicate that the PCBs present in the Acushnet Estuarine sediments do actually fall within the range of isomers represented by these two standards, thus the measurements are not low. This may be the result of degradation of the lower-chlorinated isomers in the environment, driving the average chlorine content of the mixture up. Similar historical changes in PCB composition have occurred in other estuaries (Stainken and Rollwagen, 1979; Butler and Schutzmann, 1978). In the upper reaches of the Hudson River, New York, Aroclors 1242 and 1016 constituted 90 percent of the PCBs measured, with Aroclor 1254 making up the rest. The relative percentage of Aroclor 1254, however, increased downstream (further from the PCB sources) to approximately 20 percent of the total (Bopp et al., 1981).

In contrast to the estuarine data, samples of wastewater collected from the New Bedford sewer system revealed Aroclor 1016 in higher concentrations than Aroclor 1254, and in the treatment plant sludge and effluent samples only Aroclor 1242 was found. Similarly, PCB concentrations in air samples mostly occurred as Aroclors 1016/1242, with very little Aroclor 1254. (Aroclors 1016 and 1242 are very similar in chlorine composition, with averages of 41 and 42 percent respectively, and often are not distinguishable on a chromatograph). Since the different Aroclor mixtures do not represent discrete compounds, but rather an average chlorine composition, their distinction here is made

essentially for purposes of quantification and evaluation of the overall PCB contamination problem. The distinction can not be applied when it comes to remedial action as the individual Aroclors can not be isolated, nor can it be used to conclusively link the contamination with PCB sources, due to the changes in composition which can not be quantified.

In addition to its extensive PCB contamination, the Acushnet Estuary has significantly high levels of trace metals, particularly chromium, copper, lead and zinc. It has been estimated that the three major contaminant metals, copper, chromium, and zinc, form more than one percent of the dry weight of harbor sediments (Summerhayes et al., 1977). Tables 20 and 21 summarize the metals concentrations in estuarine sediments, based on the data presently maintained in the data base file. It should be noted, however, that the metals data in the file are only those collected in conjunction with PCBs (since that was the focus of this project), and do not constitute a comprehensive metals data base. Other available metals data should be obtained and incorporated into the system. With a larger metals data base, contour maps, like those for the PCB concentrations, could be developed to determine whether the locations of metals contamination coincide with the PCB hot spots. It will be especially important in evaluating cleanup alternatives (e.g. dredging) to know where and to what extent heavy metals are present in the estuary, as they may be more easily mobilized in

TABLE 20. METALS CONCENTRATIONS IN INNER HARBOR SEDIMENTS (PPM DRY WT.), ACUSHNET ESTUARY

Metal	No. of Records	Minimum	Maximum	Median	Mean
Arsenic	54	0.1	116	6.4	12
Cadmium	54	ND	65	4.0	8.7
Chromium	54	3.9	940	110	210
Copper	54	5.3	2200	335	560
Lead	54	2.1	1400	195	320
Mercury	54	ND	24	0.3	0.9
Nickel	54	0.1	193	28	40
Selenium	--	--	--	--	--
Silver	33	ND	1437	1.9	45
Vanadium	22	5.4	150	32	43
Zinc	53	10	4400	290	700

TABLE 21. METALS CONCENTRATIONS IN OUTER HARBOR SEDIMENTS (PPM DRY WT.), ACUSHNET ESTUARY

Metal	No. of Records	Minimum	Maximum	Median	Mean
Arsenic	--	--	--	--	--
Cadmium	17	ND	23	1.1	2.7
Chromium	17	4.3	263	27	57
Copper	17	4.7	437	64	110
Lead	17	7.1	441	54	120
Mercury	17	ND	4.3	0.2	0.7
Nickel	--	--	--	--	--
Selenium	17	3.3	33	7.6	11
Silver	--	--	--	--	--
Vanadium	17	2.4	65	22	29
Zinc	17	13	693	117	180

the water column, may influence chemical reactions, and can also be extremely toxic.

There are presently no data in the system for polychlorinated dibenzofurans (PCDFs), polychlorinated naphthalenes (PCNs), polychlorinated quarterphenyls (PCQs), or polychlorinated dibenzo-dioxins (PCDDs), which have been implicated as possible contaminants and/or byproducts of PCBs. Due to the highly toxic nature of these compounds, several samples from a variety of Acushnet Estuary media (e.g. sediment, air, water) should be screened for their presence.

Critical Pathways and Fate Processes

A thorough understanding of critical pathways and fate processes is probably one of the most significant "data gaps" remaining in the Acushnet Estuary PCB issue. Although the existing data base provides a description of the PCB contamination of the Acushnet Estuary, it is a dynamic and ever-changing situtation. In order to evaluate the significance of this contamination, it is essential to identify the processes by which it is changing, and to determine which sectors of the environment are most in need of remedial action. This need has been recognized, and a comprehensive program for the investigation of biological, chemical, and geophysical pathways in the harbor has been outlined in project work statement 007 of the RAMP document (Weston, 1983). The existing data base will provide the foundation for this endeavor, and apparent trends which are described here will be investigated more fully.

The most significant PCB contamination in the Acushnet Estuary is in the bottom sediments of the Inner Harbor. In spite of the large amount of data for this area, there is presently very little known about the physical processes responsible for the transport and disturbance of these sediments. One study (Summerhayes et al., 1977) dealt primarily with the transport of heavy metals (and not PCBs) in the Outer Harbor and western Buzzards Bay. This research revealed some of the significant fundamental processes relevant to PCB transport. It determined that silt and clay from outer Buzzards Bay are transported into the harbor and trapped by the hurricane barrier at a rate of approximately 4 to 8 cm/yr in the deeps, and < 2 cm/yr in the shallows. Summerhayes et al. described the harbor as a "leaky sink" for organic and industrial contaminants.

What remains to be defined by the proposed investigation is how the sediments and thus the PCBs, are distributed and redistributed within the Inner Harbor area. The contour maps developed with the Kriging process indicate some accumulation of PCBs behind the existing barriers, however, the extent of this accumulation can not be quantified due to the paucity of data in these areas. There is, for example, no data for any sediment samples collected immediately to the north of the western segment of the hurricane barrier, although this appears to be one of the most likely places for sediment trapping to occur. The modeling of sediment transport dynamics will require additional sampling in these areas.

Although there is a substantial amount of sediment PCB data at present, there is relatively little information on the mobilization of PCBs to, and subsequent transport in, the estuarine water column. The analytical methods used in quantitating water samples from the Acushnet Estuary in the past did not permit detection of low, but highly toxic, levels of PCBs. Since the water column moves differently than the sediments (e.g. it is probably flushed more rapidly), and is a ready source of PCBs to biological organisms, it merits further investigation. Additional water sampling will also indicate whether (and where) the bottom sediments are steadily "leaking" PCBs to the water column, or whether they are being effectively capped by the natural sedimentation of cleaner materials. The few sediment elutriate data which exist at present will also be informative in this matter, however they portray more the potential for the sediments to leak PCBs to the water column than the actual exchange dynamics which take place.

Tables 17 and 18 presented earlier (pages 77 and 78) indicate the extent to which aquatic biota in the Acushnet Estuary have bioconcentrated PCBs. Due to their high lipid content and habitat, eels were the most severely contaminated of the organisms studied. Data on PCBs in lobsters and quahogs (specifically in the Inner Harbor) need to be supplemented, with investigation into the relation of PCB concentrations to organism sex and size, and seasonal migrations. This would apply to any other commercial fish species in the estuary, as there may be

times during the year when contamination is less severe and harvesting would be less of a risk to public health.

Also indicated, but not yet clearly defined, by the data base is the apparent degradation of PCBs (specifically the lower chlorinated isomers) in the estuarine environment. Photolytic decomposition and biodegration may be occurring, for example, in both the aerobic and anaerobic portions of the mudflats lining the estuary. Similarly, there has been very little effort made to relate PCB concentrations in air to those of nearby sediments and surface waters, such that the volatization from such sources could be quantified. It is anticipated that the significance of this and other PCB pathways will be identified in the modeling investigations.

Implications of Contamination

Table 22 presents a summary of the regulatory limits and standards relevant to PCBs. The Toxic Substance Control Act (TSCA), 40 CFR Part 761, defines a PCB - contaminated waste as one that contains PCBs at a concentration between 50 and 500 ppm, and a PCB waste as that which contains PCBs greater than 500 ppm. TSCA (40 CFR Part 761.65) also provides extensive requirements for storage of PCBs in concentrations exceeding 50 ppm, including specifications for storage facility, the PCB containers, handling equipment, marking of PCBs, a Spill Prevention and Control Plan, and location at a site not below the 100 year flood plain. Based on the information presented in Figures 14 through 21, a substantial portion of the sediments underlying the Inner New

TABLE 22. PCB LIMITS AND STANDARDS

Regulation/ Controlling Agency	Media	Level	Action
TSCA, (40 CFR, Part 761)	PCB-contaminated waste	50-500 ppm (dry weight)	must be disposed of by chemical waste landfilling or Annex I incineration.
	PCB waste	> 500 ppm (dry weight)	must be disposed of by Annex I incineration.
USFDA (44 CFR, 57389, 1979)	Foodstuffs: fish & shellfish (edible portion)	5.0 ppm* (wet weight)	maximum allowable level for the protection of public health.
	red meat (fat basis)	3.0 ppm (wet weight)	maximum allowable level for the protection of public health.
	poultry (fat basis)	3.0 ppm (wet weight)	maximum allowable level for the protection of public health.
EPA Criteria, 1981 (P.L. 95-317, Section 304(a)(1)	Ambient Water	0.014 $\mu g/l$	maximum level for protection to freshwater fish.
		0.030 $\mu g/l$	maximum level for protection to saltwater fish.
		0.000 $\mu g/l$	maximum level for protection to human health.
NIOSH	Workroom air	1 $\mu g/m^3$	maximum recommenced concentration for protection of health.

*USFDA lowered this standard to 2 ppm in 1979, however challenges by the seafood industry have resulted in a temporary stay placed on the standard by the courts.

Bedford Harbor are categorized as PCB wastes and PCB-contaminated wastes under TSCA. The fact that any of this material dredged from the harbor will require special disposal as a hazardous waste will have significant implications as to the cost and efficiency of employing dredging as a remedial action.

Based on the data summarized in Tables 17 and 18, median PCB concentrations in eels and lobsters in the Acushnet Estuary are well above the FDA action level of 5 ppm, which is the maximum PCB concentration considered safe for human consumption. Although there are no lobster data for the Inner Harbor, this can be assumed to apply to both the Inner and Outer Harbor areas. PCB concentrations in lobsters taken from further out into Buzzards Bay are also higher than 5 ppm. The median PCB concentration in winter flounder is above the FDA limit only in the Inner Harbor, although in the Outer Harbor, flounder PCB concentrations are above FDA'S recommended limit of 2 ppm. Median PCB concentrations in quahogs from these areas are not above the FDA limit, however there are only three data records for quahogs in the Inner Harbor area.

Based on these data summaries, the fishing closure areas established by the Massachusetts Department of Public Health appear to be appropriate. These closures prohibit all fishing activity in the Inner Harbor area (Area 1); fishing for lobsters, eels, flounder, tautog and scup in the Outer Harbor area (Area 2, extending to the Ricketsons Point/Wilbur Point transect): and lobster fishing inside of Negro Ledge (Area 3).

The EPA criteria for PCB in ambient water are 0.014 ug/l to protect freshwater fish, 0.030 ug/l to protect saltwater fish, and zero for maximum protection of human health (U.S. EPA 1980). These concentrations are average 24-hour values. Ambient water PCB concentrations measured in the Acushnet River in 1981 were mostly "non detectable", but were based on a detection limit of 0.5 ug/l. Measurable concentrations ranged as high as 6.1 ug/l. Thus, the average 24-hour concentration of PCBs in the Acushnet Estuary waters may well be far in excess of the EPA criteria.

Effectiveness and Impacts of Potential Cleanup Alternatives

The color contour maps portraying PCB concentrations in the sediments of the Acushnet Estuary (Figures 14 through 21) delineate several "hot spot" areas applicable to fast track remedial action. The maps also indicate that the most severely contaminated sedments lie approximately 4 to 8 cm deep, an important fact in planning remedial operations and in evaluating the potential natural capping processes in the harbor.

The proposed modeling of sediment transport and PCB dynamics for the estuary will provide much of the information crucial to the planning of remedial action alternatives. In addition, the further resolution of sediment PCB concentrations in areas not well sampled, and the addition of more metals data to the data base, will permit the development of more comprehensive, and statistically significant, contour maps delineating areas requiring remedial action.

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APPENDIX A

APPENDIX A

DATA MANAGEMENT SYSTEM

SUMMARY OF FILE CONTENTS

Sample Types

Air

Aquatic biota
- Argopecten irradians (Bay scallop)
- Anguilla rostrata (American eel)
- Cerianthus americanus (polychaete)
- Callinectes sapidus (Blue crab)
- Centropristis striata (Black seabass)
- Crassostrea virginica (American oyster)
- Geukensia demissa (Ribbed mussel)
- Homarus americanus (American lobster)
- Ioligo peali (Long-finned squid)
- Mya arenaria (Softshell clam)
- Merluccius bilinearis (Silver hake)
- Mustelus canis (Smooth dogfish)
- Mytilus edulis (Blue mussel)
- Mercenaria mercenaria (Quahog)
- Morone saxatilis (Striped bass)
- Nephtys incisa (polychaete)
- Neopanope texana (Mud crab)
- Osmerus mordax (American smelt)
- Pseudopleuronectes americanus (Winter flounder)
- Prionotus carolinus (Sea robin)
- Paralichthys dentatus (Summer flounder or Fluke)
- Paralichthys oblongus (Fourspot flounder)
- Pomatomus saltatrix (Bluefish)
- Peprilus triacanthus (Butterfish)
- Raja erinacae (Little skate)
- Scophthalmus aquosus (Windowpane)
- Stenotomus chrysops (Scup)
- Tautogolabrus adspersus (Cunner)
- Tautoga onitus (Tautog)
- Urophycis chuss (Red hake)

Grit
Miscellaneous
Sediment
Sediment elutriates
Sediments - EP Toxicity
Soil
Waste
Waste - EP Toxicity
Water

Sample Sources

Ambient air
Apponcgansett River Basin
Ash
Buzzards Bay
Clarks Cove
Cooling water
Edible meat (eg. lobster claw)
Flesh
Grit
Groundwater
Inner Harbor (New Bedford)
Industrial wastewater
Land
Mount Hope Bay, Fall River
Miscellaneous
Outer Harbor (New Bedford)
Raw drinking water
River
Raw wastewater
Sludge
Treated wastewater
Viscera
Whole organism (without shell)
Waste
General wastewater

Exact Sources

Deep (>8 cm for sediments)
Downwind
Mid-depth (Water)
Shallow (4-8 cm for sediments)
At the source (air)
Surface (0-4 cm for sediments)
Upwind

Units

No units(or non-detectable)
Millivolts
Nanograms per cubic meter
Parts per million (ppm)
Parts per million (ppm) dry weight
Parts per million (ppm) wet weight

Parameters

PCBs
- Aroclor 1221
- Aroclor 1232
- Aroclor 1016
- Aroclor 1242
- Aroclor 1248
- Aroclor 1254
- Aroclor 1260
- Aroclor 1262
- Aroclors 1242/1016
- Aroclors 1242/1254
- Aroclors 1248/1260
- Aroclors 1248/1254
- non-specific PCBs
- Total PCPs

Metals
- Arsenic
- Cadmium
- Chromium
- Copper
- Lead
- Barium
- Mercury
- Nickel
- Selenium
- Silver
- Thallium
- Zinc
- Cobalt
- Iron
- Vanadium

Miscellaneous
- Chemical Oxygen Demand
- Redox potential
- Oil & grease
- Phenol

Data Collecting Agencies

Army Corps of Engineers
Aerovox Incorporated
Camp, Dresser & McKee
Cornell-Dublier Electronics
Jason Cortell & Associates
Massachusetts Office of Coastal Zone Management
Massachusetts Department of Environmental Quality Engineering
Division of Water Pollution Control
Massachusetts Division of Marine Fisheries
U.S. Environmental Protection Agency -- Region I
Fairhaven Marine
U.S. Food and Drug Administration
GCA Corporation
Gidley Laboratories
Massachusetts Department of Public Health
Massachusetts Department of Public Works
New England Governor's Conference, Inc.
Southeastern Massachusetts University
Tibbetts Engineering Corp.
University of South Carolina
Woods Hole Oceanographic Institute

Analytical Laboratories

Cambridge Analytical Associates
Cat Cove Marine Lab (DMF)
Camp, Dresser & McKee
Jason M. Cortell & Associates
U.S. EPA -- Region I (Lexington, MA)
Energy Resources Company
Environmental Science & Engineering
FDA -- Boston District Office
GCA Corporation
Gidley Laboratories
Lawrence Experiment Station (DEQE)
Lycott Environmental Research, Inc.
Massachusetts Department of Public Health
Monsanto Corporation
New England Aquarium
New England Analytical & Testing Lab
Southeastern Massachusetts University
Tibbetts Engineering Corporation
University of South Carolina
U.S. Coast Guard
Versar
Woods Hole Oceanographic Institute
Woodson - Tenet Laboratories

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